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IRRIGATION AND COLLECTION FACILITIES FOR SOUTHEASTERN MICHIGAN --ETC(U)
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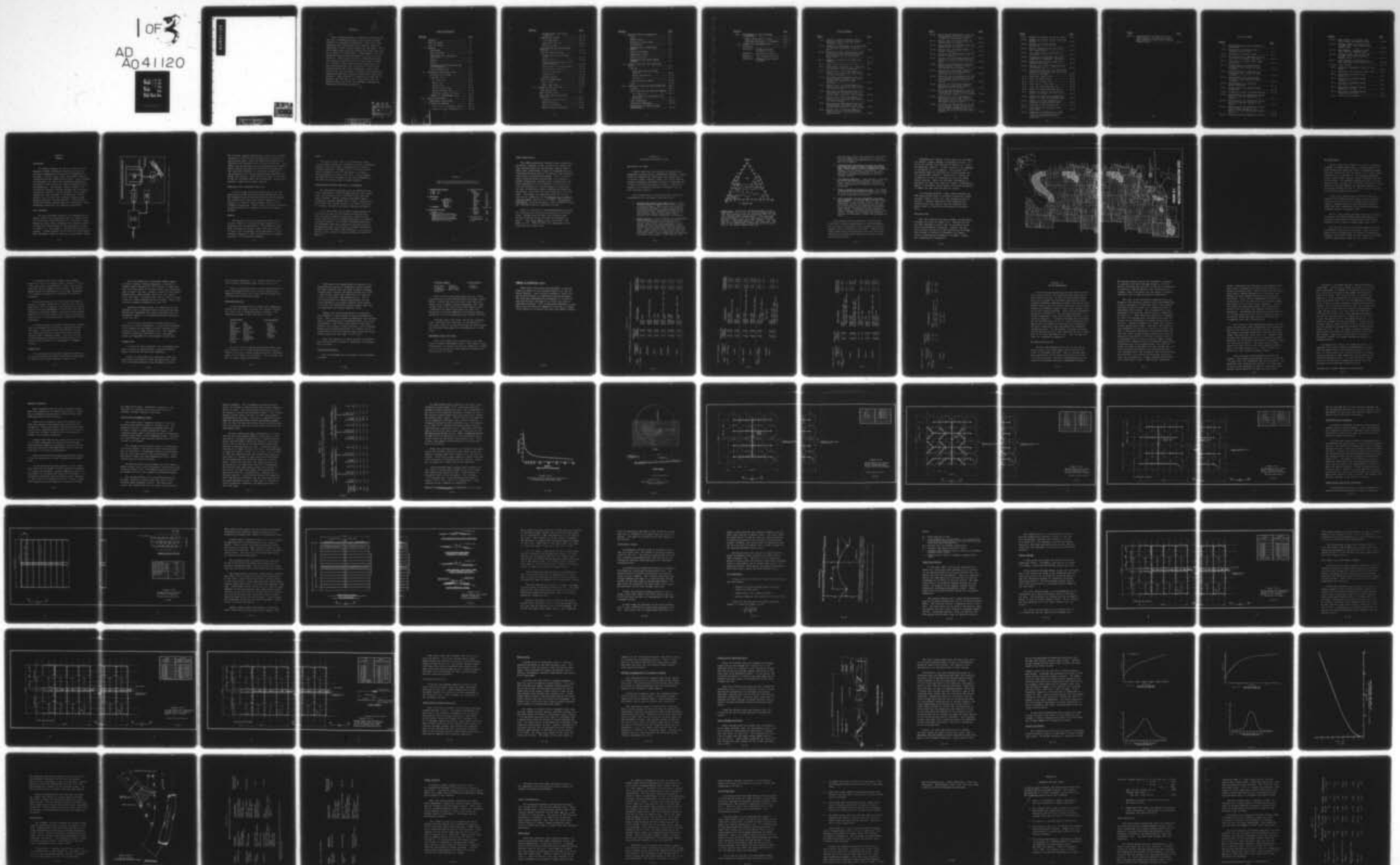

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ABSTRACT

Four irrigation sites in Southeastern Michigan and one site in Northwestern Ohio were selected as being suitable for wastewater renovation. These five sites represent about 1100 square miles and will treat the equivalent of 3366 million gallons per day (MGD). Wastewater application rate will average two inches per week for 35 weeks (70 inches/year). Crops grown on the irrigated land are grasses and legumes in a 10-or 12-year rotation. Total capital cost for irrigation and percolate collection facilities on the five sites is about $1.7 billion. Annual operation and maintenance cost and total annualized cost are about $57 and $137 per million gallons of treated wastewater, respectively. Costs do not include sewage collection and transmission, lagoon treatment and storage, disinfection, and sludge disposal. Land treatment is expected to remove 98% of the BOD, 95% COD, 85% N, 99% P, 95% metals, 99% suspended solids, and 99% of the pathogens contained in Southeastern Michigan wastewater.

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SECTION I
GENERAL

BACKGROUND

The Detroit District of the U. S. Army Corps of Engineers (CORPS) conducted a feasibility study on wastewater management alternatives for Southeastern Michigan. Various local, state, and federal agencies cooperated with the CORPS on this study. Land treatment of wastewaters was one of the promising alternatives concluded in the feasibility study to warrant further investigations. Accordingly, several studies were initiated to develop technical designs and to evaluate ecological, hygienic, social, aesthetic and economic impacts for land treatment of wastewaters. Similar studies were initiated for advanced biological and physical-chemical treatment methods. These methods along with various combinations are considered as other promising alternatives for managing wastewaters.

LAND TREATMENT

The land treatment alternative for managing wastewaters allows soil and growing plants to remove potential pollutants before the water is collected in underdrains for reuse and/or discharge into streams or lakes. A simplified flow diagram for land treatment is shown in Figure I-1. Raw sewage is collected and treated in lagoons. Storage lagoons are provided for winter months when wastewater cannot be applied to agricultural lands.

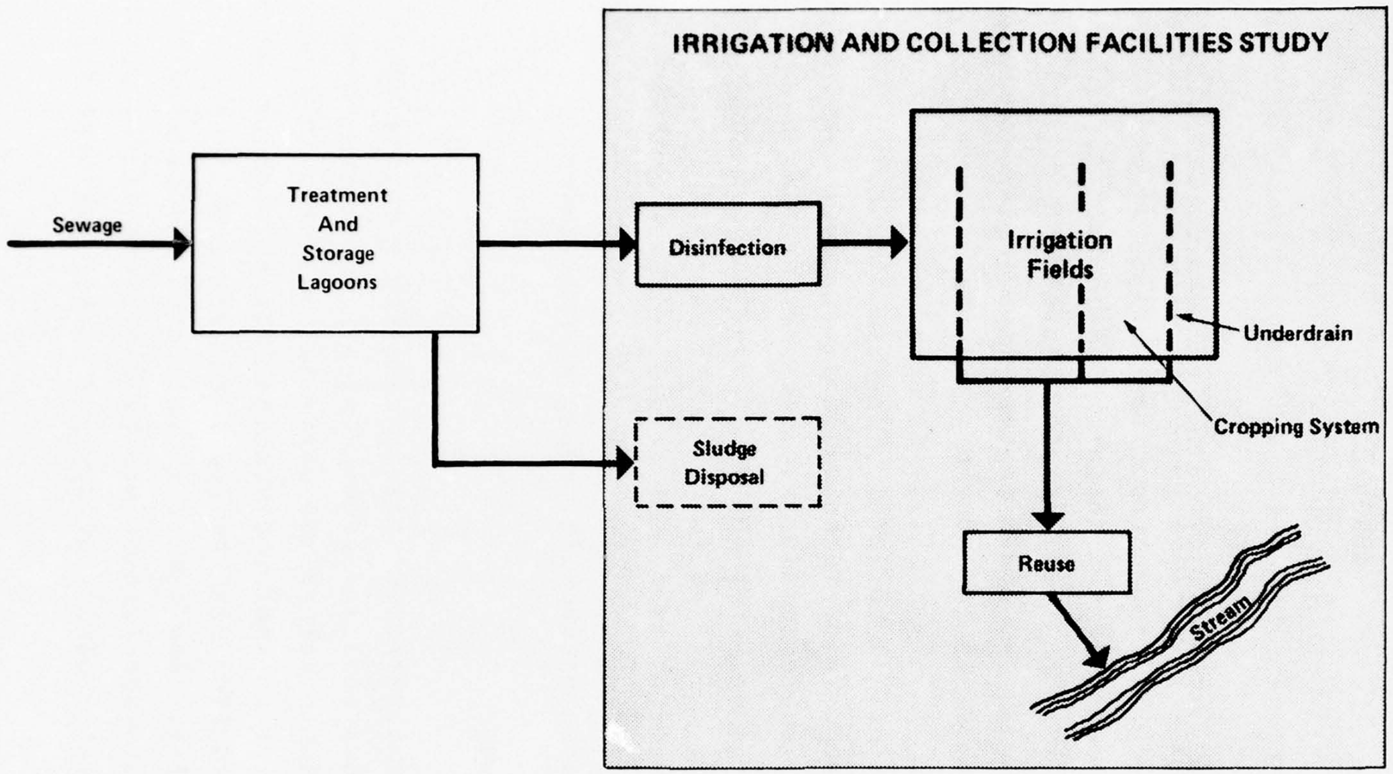


Figure I-1 Flow Diagram for Land Treatment of Wastewater

The effluent, usually equivalent in quality to secondary treatment, is disinfected and applied by irrigation to agricultural lands. The soil removes nutrients, micro-organisms and suspended solids from the wastewater. Also, plants take up nutrients and soil microorganisms consume organic matter originally contained in the wastewater. The renovated wastewater is collected in underdrains and transported to reuse facilities before possible discharge into streams. Reuse facilities might be designed to use the renovated water for recreational, aesthetics, wildlife, industrial or other purposes.

IRRIGATION AND COLLECTION FACILITIES

In this study, collection facilities are for the renovated water which has percolated through the soil. The Irrigation and Collection Facilities Study excludes the collection of raw sewage and the lagoon system (Figure I-1) from the land treatment alternative of wastewater management. Other studies are being conducted to develop designs for sewage collection and lagoon systems.

PURPOSE

The purpose of the Irrigation and Collection Facilities Study is to develop designs suitable for estimating costs and performance. The CORPS will integrate information from this study with other studies to fully assess advantages and disadvantages of land treatment compared to other alternatives for managing wastewater in Southeastern Michigan.

SCOPE

The scope of the study is to develop conceptual or preliminary designs for irrigation systems, groundwater control, reuse facilities, stream outfalls, and agricultural practices. Designs will be of sufficient detail to estimate costs with the degree of accuracy usually found in a survey scope study. Also, designs will meet the more stringent of the state standards or the CORPS prescribed goals for water quality.

SOUTHEASTERN MICHIGAN AREA AND ITS WASTEWATER

The Southeastern Michigan area, as defined by the CORPS, represents a total drainage area of 5,372 square miles and includes all or a portion of the following eight counties: Monroe, Lenawee, Washtenaw, Wayne, Livingston, Oakland, Macomb and St. Clair. Major cities within this area include Detroit, Port Huron, Pontiac, Mt. Clemens, Ann Arbor, Ypsilanti, Adrian, and Monroe.

In the year 1990, nearly three billion gallons of wastewater per day will be produced within the area. This wastewater represents municipal, industrial and urban storm flows and is assumed equivalent to secondary treatment effluent. For design and planning purposes, the wastewater from the Southeastern Michigan area was assumed equivalent to the typical secondary effluent as defined by the USA CRREL study team (82). The characteristics of this typical secondary effluent are shown in Table I-1.

This table from CRREL

Table I-1

Typical Secondary Effluent Characteristics
(All as mg/liter unless otherwise noted.)

I. Oxygen-demanding compounds

a. BOD 25
b. COD 70

II. Biostimulants

a. Nitrogen	Total N	20
	Organic	2.0 (as N)
	$+NH_4$	9.8 (as N)
	$-NO_2$	0.0 (as N)
	$-NO_3$	8.2 (as N)
b. Phosphorus	Total P	10

III. Other organic compounds

a. Phenols 0.3
b. Chlorinated and other complex organics – (Concentrations vary. Total concentration of these refractory organics approaches 45 mg/liter as indicated by the difference between COD-BOD results above.)

IV. Inorganic compounds

a. Metals	
Cadmium	0.1
Chromium	0.2
Copper	0.1
Iron	0.1
Lead	0.1
Manganese	0.2
Mercury	5 ppb.
Nickel	0.2
Zinc	0.2
Sodium	S.A.R. = 4.6
b. Non metals	
Boron	0.7
Chlorides	100
Sulfate	125

V. Other characteristics

a. Suspended solids	25
b. pH	7.0

STUDY ORGANIZATION

The CORPS tentatively selected lands suitable for wastewater treatment in the vicinities of Armada Township, Macomb County and Ida Township, Monroe County. These lands represented a range in topography and soil conditions believed typical of potential land treatment sites within Southeastern Michigan. Those sites were used to develop design alternatives for irrigation method, underdrains, farming, water transmission, and other components of the irrigation and collection facilities necessary for land treatment of wastewater. The work on developing design alternatives along with preliminary site selections constituted Phase I of the study. This phase was completed within 60 calendar days and was summarized in the Advance Copy of the Preliminary Report submitted to the CORPS. The Preliminary Report, covering the Phase I work in greater detail, was forwarded within an additional 30 days.

Phase II consisted of developing designs and costs for irrigation and collection facilities at five locations. Designs used at these five locations were selected from the design alternatives developed in Phase I. This Final Report covers both Phase I and Phase II work. Time available for completion of the study was 183 calendar days.

SECTION II
WASTEWATER IRRIGATION SITES

SUITABILITY OF LANDS

Sizable land areas are required to renovate the wastewater produced within Southeastern Michigan. Hence, lands were examined for functional and economic merits in Tuscola, Huron, Sanilac, Lapeer, St. Clair, Macomb, Lenawee, Washtenaw, and Monroe counties in Michigan and in Fulton and Williams counties in Ohio. Lands were examined for potential wastewater treatment sites in only the above counties.

Soil characteristics selected to give functional acceptability for wastewater renovation were:

1. Mineral soil rather than organic soil. Small isolated areas of organic soils exist in Southeastern Michigan. These areas were rejected to maintain uniformity in the engineering designs and agricultural programs required for the mineral soils. Organic soils have poorer load bearing capacity and perhaps lower affinity for certain wastewater constituents.

2. Medium texture. Soil adsorption of constituents from solution generally increases with clay fraction and organic matter contents (82). Medium texture soils were selected as being optimum for both adsorbing wastewater constituents and having acceptable water permeability rates. Coarse texture soils such as sands and loamy sands (Figure II-1) have lower clay contents and hence a lower probability of adsorbing wastewater constituents. Fine texture soils

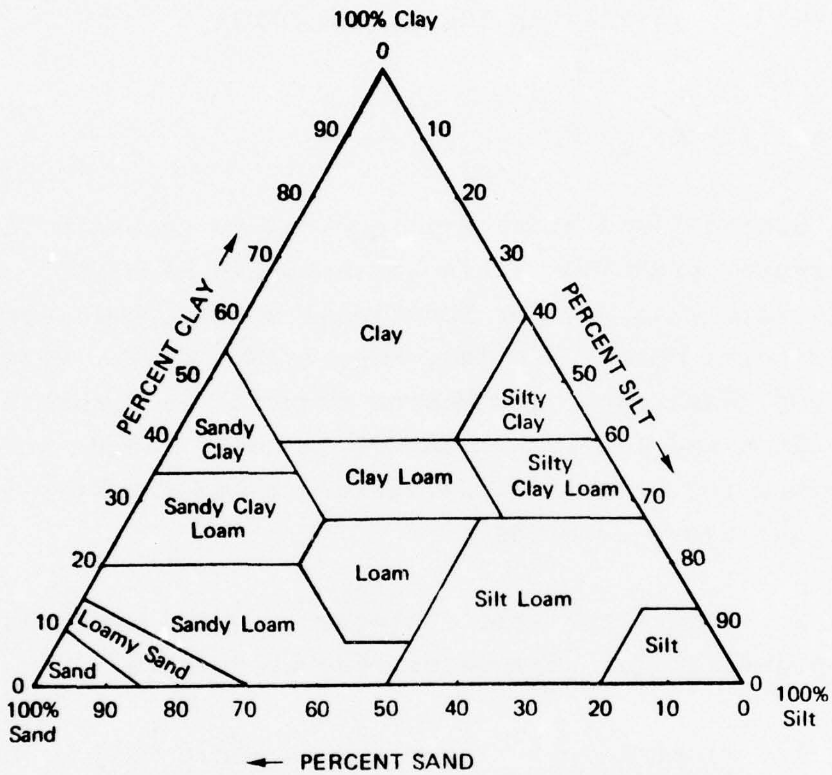


Figure II-1. Diagram for determining USDA textural name of soil (50). Silt and clay percentages for the soil under consideration are located on the silt and clay triangle sides, respectively. Lines are then projected inward. For silt, the line is projected parallel to the clay side of the triangle. For clay, the line is projected parallel to the sand side. The name of the compartment in which the two lines intersect is the texture name of the soil.

such as clay, silty clay, and sandy clay adsorb the constituents but usually have low permeabilities making them unsuitable for land treatment of wastewater.

3. Permeabilities exceeding 0.6 in/hr in surface soil horizon and 0.2 in/hr in subsurface horizons. This surface horizon permeability permits adequate initial uptake of wastewater. The subsurface horizon permeability is minimal to maintain acceptable performance of the tile drainage system.

4. Crop growth potential. Plant growth is required to assist the soil in wastewater renovation. Hence, toxic soil concentrations of alkali or other materials must be absent to insure crop production.

5. Depth to bedrock exceeding 10 feet. This depth is desired for installing the underdrain system. At least five foot depth of aerobic soil is desired for wastewater renovation.

6. Level to gently rolling topography with minimal woodland. Six percent was selected as the upper limit for acceptable slopes. Areas with predominant slopes exceeding 6% increase the difficulty and cost of constructing an underdrain system and controlling soil erosion and water runoff. Irrigation systems requiring graded surfaces are adversely affected by steep slopes. Minimal land leveling and woodland clearing are desired to reduce site preparation costs.

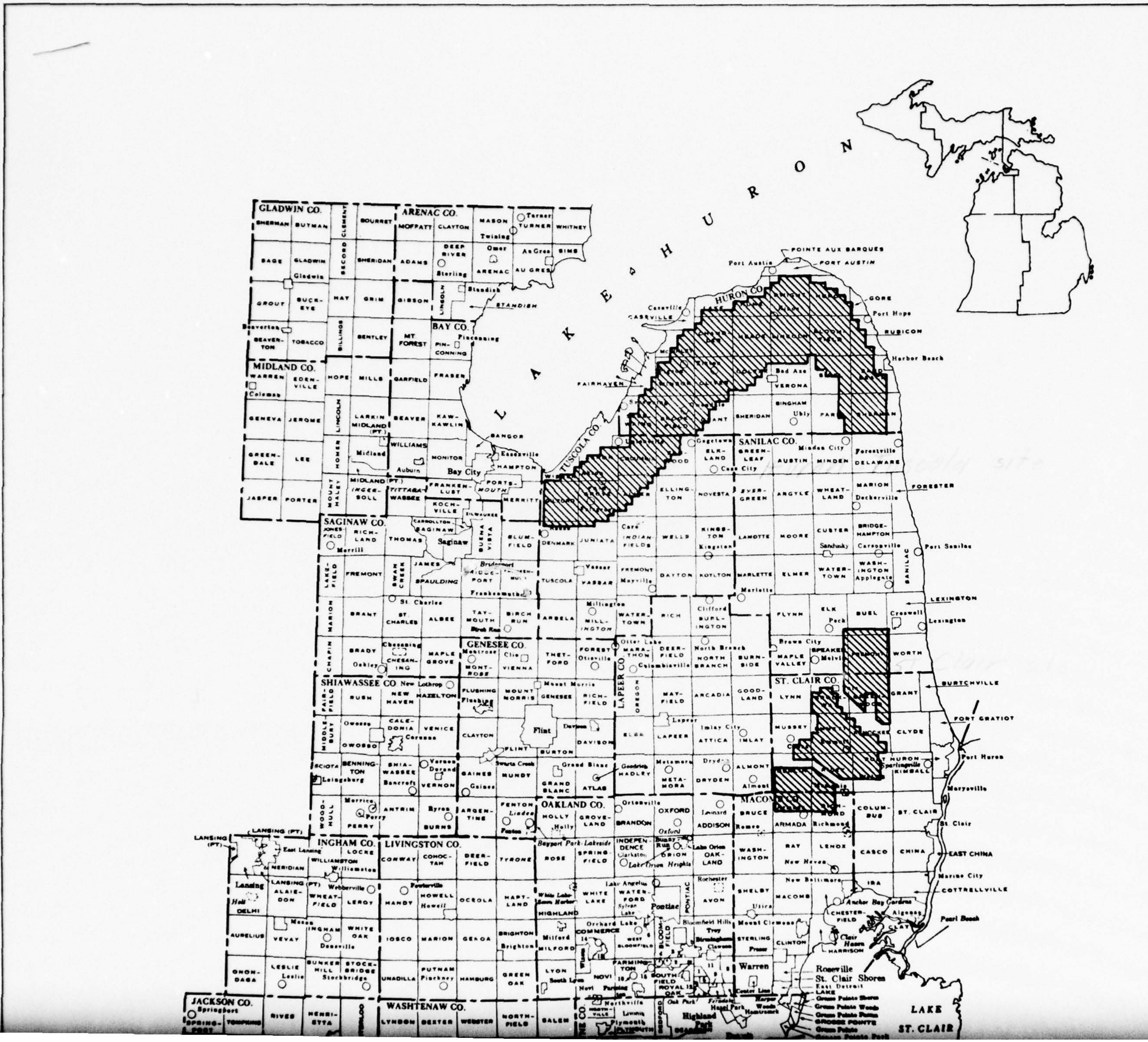
Soil characteristics were determined from published soil surveys, unpublished soil data possessed by local Soil Conservation Service groups and from geological studies sponsored by the CORPS. Additionally, field inspections and interviews with local and state university personnel were conducted to verify certain soil characteristics.

Published soil surveys (recent years) are available for Sanilac, Lapeer, Macomb, and Lenawee counties. Interim soil surveys were obtained for Monroe, St. Clair, and Washtenaw counties. In these counties, soil mapping is incomplete or is in progress. Only general soil association maps were obtained for Tuscola, Huron, Fulton and Williams counties. Detailed soil surveys are in progress or have not been made recently for these latter counties. More soil and other information is available for some sites than from others. Consequently, degree of confidence on wastewater renovation suitability is higher for some counties than for others.

In selecting potential sites, lands projected for 1990 urban growth areas or presently containing sizable villages, towns, cities, etc. were avoided as much as possible. Further, land areas with acceptable soil characteristics but smaller than one township (~36 square miles) in size were not selected as potential sites.

SELECTED SITES

The sites selected as being suitable for wastewater treatment are shown in Figure II-2. Substantially all the land contained in these sites is considered to be usable for wastewater irrigation. However, the net area actually available for the construction of irrigation systems is reduced by allowances for "buffer strips" bordering major highways, railroads, streams and irrigation site boundaries.


LAKE HURON
GLADWIN CO.
ARENAC CO.
BAY CO.
MIDLAND CO.
SAGINAW CO.
TUSCOLA CO.
HURON CO.
SANILAC CO.
GENESEE CO.
LAPEER CO.
ST. CLAIR CO.
SHIAWASSEE CO.
OAKLAND CO.
MACOMB CO.
INGHAM CO.
LIVINGSTON CO.
JACKSON CO.
WASHTENAW CO.
LAKE ST. CLAIR
Bay City
Saginaw
Flint
Port Huron
Port Austin
Harbor Beach
Lexington
Port Sanilac
Pontiac
Warren
Roseville
St. Clair Shores
Lansing

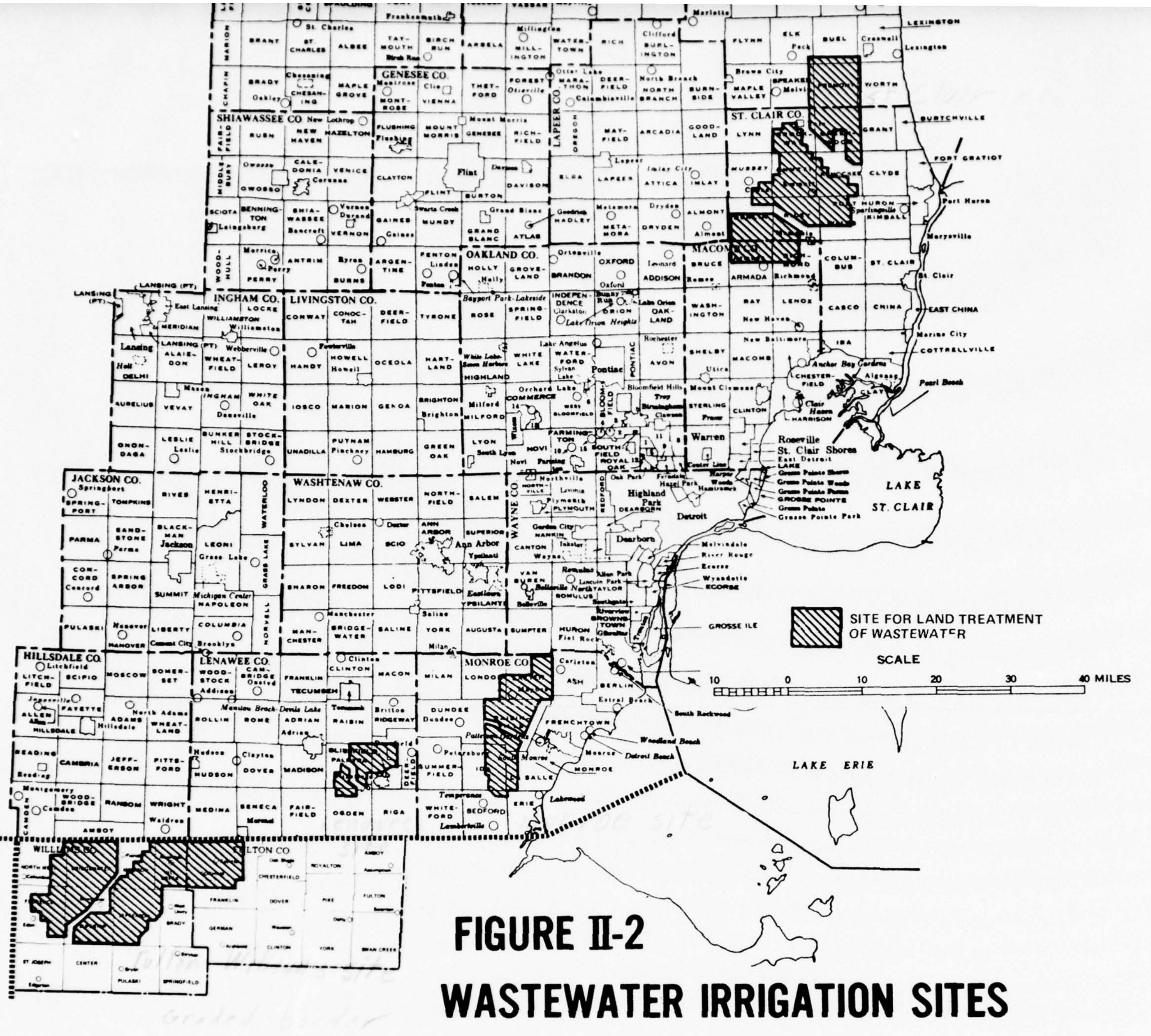


FIGURE II-2

WASTEWATER IRRIGATION SITES

St. Clair Site

The St. Clair site (Figure II-2) has its southern boundary in Macomb County where it includes half of Armada Township and about one-fourth of Richmond Township. The major portion of the site exists in St. Clair County, consuming all or portions of the following townships: Berlin, Riley, Wales, Mussey, Emmett, Kenockee, Brockway and Greenwood. The northern extension of the site into Sanilac County includes all of Fremont Township and small portions of Valley, Melvin, Elk and Buel townships. A large area northwest of the St. Clair site was reserved for potential sludge disposal use.

Soils in the Macomb County portion of the site belong to the Conover-Parkhill-Locke soil association. These soils are described as "nearly level to gently sloping, somewhat poorly drained and poorly drained soils that have a moderately fine textured and medium-textured subsoil; on uplands" (48).

The St. Clair County portion of the site is characterized by the Conover-Blount-Parkhill-Metamora soil association described as "somewhat poorly and poorly drained, level to gently sloping loamy soils" (69).

The soils of the site in Sanilac County belong to the Parkhill-Capac soil association. These soils are nearly level to undulating, very poorly to imperfectly drained, dark grayish-brown to black, neutral and mildly alkaline sandy loams, loams and clay loams (64).

A prominent sandy beach ridge at the southern boundry of the site in Macomb County separates it from a few square miles of potentially useful site land between the towns of Armada and Ray Center. The rest of Macomb County has undesirable soils, rough topography or is presently urbanized or projected for urban development.

The western part of St. Clair County was omitted because of organic (muck) soils, and Hoytville and Nappanee soils that are present. The latter soils are considered to be too impermeable for efficient use with an underdrain collection system. The eastern and southern portions of St. Clair County were considered unsuitable areas because of urban projections, undesirable soils, or topography.

In Sanilac County, a random distribution of organic soils discouraged the selection of considerably more site land. A long thin strip of potentially useful site land runs parallel to and just inland from the eastern shore of Sanilac County. This area was not included among preliminary site lands because of its narrow width and much of its topography is somewhat rolling.

Monroe Site

The indicated site includes substantial portions of Ida, Rasinville and Exeter townships and small parts of Bedford and LaSalle townships (Figure II-2).

Soils are primarily the Selfridge-Pewamo complex on level to gently sloping topography. Selfridge is somewhat poorly drained with 20-40 inches of loamy sand over clay loam, about 10-18 inches thick, over calcareous loam to light clay loam. Pewamo is poorly to very poorly drained with a loamy surface layer over clay loam to silty clay loam. Calcareous clay loam to silty clay loam occurs at a depth ranging from 30-42 inches. These soils are mixed together throughout the site (74).

Southeastern Monroe County, including much of the indicated site, is underlain with a fractured limestone bedrock that approaches the surface near Lake Erie (74). Groundwater quality is a recognized problem, especially in the Ida area.

The area east and south of the described site is projected for urban development. An area with acceptable soils northwest of the Monroe site was reserved for potential use as a sludge disposal site. The remainder of Monroe County has undesirable soils, some quite sandy, and topography is objectionable in some areas.

Lenawee Site

A relatively small potential site is located southeast of Adrian in Lenawee County, involving Palmyra, Ogden, Blissfield and Deerfield townships.

Macomb is the primary soil indicated in the soil association described as "level and undulating, imperfectly and poorly drained soils developed in deltaic

and lucustrine deposits" (78). Macomb and Brady soils occur together throughout much of the Lenawee site.

There is much more land in Lenawee County that has level topography but the soils were not appropriate. Nappanee and Hoytville soils were the main reasons for rejecting many of the level lands.

Huron-Tuscola Site

A long continuous belt of nearly level topography inland from Lake Huron, accounts for the major portion of a large site in Huron and Tuscola counties. The townships involved in this site are as listed.

Huron County		Tuscola County
Sherman	Lake	Wisner
Paris	Hume	Akron
Sigel	McKinley	Columbia
Sand Beach	Chandler	Elmwood
Lincoln	Meade	Gilford
Bloomfield	Fair Haven	Fairgrove
Rubicon	Winsor	Almer
Dwight	Oliver	Denmark
Huron	Sebewaing	Juniata
Caseville	Brookfield	
Colfax	Grant	
Verona		

The site soils in Tuscola and northern Huron counties belong to a soil association described as poorly drained soils with a loamy surface layer over calcareous loams or clay loams; on till plains. Soils include variants of Londo, Tappan and Parkhill.

Other major soil associations are present in the Huron-Tuscola site but in relatively smaller amounts. The Kibbie-Colwood soils are level to gently sloping, somewhat poorly drained and poorly drained soils with a loamy surface layer over stratified silt and fine sands; on lake plains and outwash plains. Similar soils associated in a natural toposequence are the poorly drained to very poorly drained, dark-colored Bach soils, the imperfectly drained Sanilac soils and the moderately well drained Gagetown soils.

Another soil association present in relatively small amounts is characterized by Boyer and Mancelona soils. These are well drained to moderately well drained, level to undulating soils on outwash plains, lake plains and moraines. The surface sandy loam or loamy sand is underlain with loamy to clayey material, sand and gravel. Another soil association present to a limited extent is represented by Iosco and Brevort soils, which are poorly drained sands over clay loams (71,42,72,17).

Other site prospects in Huron and Tuscola counties were rejected mainly because of topography, soil permeability or both.

Fulton-Williams Site

The site includes all or portions of the following townships:

Williams County		Fulton County
North West	Madison	Gorham
Florence	Jefferson	Franklin
Bridgewater	Mill Creek	
Superior		

Soils of this site belong mostly to two closely associated soil areas, Morley-Blount and Blount-Pewamo-Morley. Within the site, the soils occur mainly on nearly level to gently sloping topography, have loamy surfaces over silty clay or clay loam subsoils, with a substratum of highly calcareous clay loam till. Blount and Pewamo are imperfectly and poorly drained and Morley soils are moderately well drained (68,7,19).

Williams County soil areas outside the indicated site, contained soils that were too impermeable or too sandy. Much of the unused portion of Fulton County has acceptable topography but a predominance of sandy soils.

Washtenaw County (No Site)

Only a few square miles of potential site land could be found in Washtenaw County. The amount of such land present in a given area was not judged to be enough to utilize efficiently in the proposed wastewater disposal system (75,76,85).

SUMMARY OF PREDOMINANT SOILS

Most soils found within the wastewater irrigation sites are medium to fine textured (Table II-1) and are poorly drained. From a texture standpoint, these soils are believed capable of renovating applied wastewater. The soils have permeabilities exceeding 0.8 in the surface horizon and a minimum of 0.2 inches per hour in subsurface horizons. With a functional underdrain system, these soils are believed capable of receiving an average of two inches of wastewater per week plus normal rainfall.

Table II-1

Summary of Predominant Soils Occurring in Proposed Wastewater Irrigation Sites

Site	Predominant Soils	Depth From Surface (Inches)	USDA Texture	Permeability (Inches/Hour)
St. Clair	Conover	0 - 12	Loam	0.8 - 2.5
		12 - 30	Clay loam	0.2 - 0.8
		30 - 60	Loam	0.8 - 2.5
	Parkhill	0 - 12	Loam	0.8 - 2.5
		12 - 36	Heavy loam and clay loam	0.2 - 0.8
		36 - 60	Loam	0.8 - 2.5
	Locke	0 - 12	Sandy loam	2.5 - 5.0
		12 - 29	Loam	0.8 - 2.5
		29 - 50	Sandy loam	2.5 - 5.0
	Blount	0 - 8	Loam	0.8 - 2.5
		8 - 28	Heavy silty clay loam, clay loam	0.2 - 0.8
		28 - 42	Clay loam	0.2 - 0.8
	Metamora	0 - 26	Sandy loam	2.5 - 5.0
		26 - 32	Light loam	0.8 - 2.5
		32 - 48	Clay loam	0.2 - 0.8
		48 - 60	Loam	0.8 - 2.5
	Capac	0 - 12	Fine sandy loam, sandy loam	2.5 - 5.0
		12 - 34	Clay loam	0.2 - 0.8
		34 - 48	Loam	0.8 - 2.5

Table II-1 (Cont'd)

Site	Predominant Soils	Depth From Surface (Inches)	USDA Texture	Permeability (Inches/Hour)
Monroe	Selfridge	0 - 29	Loamy sand	5.0 - 10.0
		29 - 42	Clay loam	0.8 - 2.5
		42 - 60	Loam or light clay loam	0.2 - 0.8
	Pewamo	0 - 11	Loam	0.8 - 2.5
		11 - 34	Clay loam, clay	0.2 - 0.8
		34 - 48	Clay loam	0.2 - 0.8
Lenawee	Macomb	0 - 11	Sandy loam	2.5 - 5.0
		11 - 30	Heavy loam and gravelly clay loam	0.8 - 2.5
		30 - 42	Loam	0.8 - 2.5
	Brady	0 - 22	Loamy sand	2.5 - 10.0
		22 - 48	Sandy loam	0.8 - 2.5
		48 - 60	Stratified sand and gravel	>10.0
Huron-Tuscola	Londo (London)	0 - 10	Loam	0.8 - 2.5
		10 - 20	Clay loam	0.8 - 2.5
		20 - 60	Loam, light clay loam, or silt loam	0.2 - 0.8
	Parkhill		(See above)	
	Kibbie	0 - 11	Loam	0.8 - 2.5
		11 - 19	Heavy silt loam	0.8 - 2.5
		19 - 34	Light silty clay loam	0.2 - 0.8
		34 - 42	Stratified silt, fine sand, and very fine sand	0.8 - 2.5

Table II-1 (Cont'd)

Site	Predominant Soils	Depth From Surface (Inches)	USDA Texture	Permeability (Inches/Hour)
Huron-Tuscola	Colwood	0 - 18	Loam	0.8 - 2.5
		18 - 32	Light silty clay loam	0.2 - 0.8
		32 - 48	Stratified silt loam, silt, fine sand, and very fine sand	0.8 - 2.5
	Boyer	0 - 15	Loamy sand	2.5 - 10.0
		15 - 24	Sandy loam	2.5 - 5.0
		24 - 30	Gravelly sandy clay loam	2.5 - 5.0
		30 - 48	Stratified sand and gravel	>10.0
	Mancelona	0 - 48	Loamy sand and gravelly loamy sand	5.0 - 10.0
		48 - 60	Silty clay loam	0.2 - 0.8
	Iosco	0 - 14	Loamy sand	5.0 - 10.0
		14 - 30	Sand	10.0
		30 - 42	Silty clay loam	0.2 - 0.8
	Brevort	0 - 22	Loamy sand and loamy fine sand	5.0 - 10.0
		22 - 28	Sandy loam	2.5 - 5.0
		28 - 34	Sand and gravel	>10.0
		34 - 44	Clay loam	0.8 - 2.5

Table II-1 (Cont'd)

Site	Predominant Soils	Depth From Surface (Inches)	USDA Texture	Permeability (Inches/Hour)
Fulton-Williams	Morley	0 - 9	Loam	0.8 - 2.5
		9 - 32	Silty clay loam, clay loam, or silty clay loam	0.2 - 0.8
		32 - 60	Silty clay loam or clay loam	0.2 - 0.8
	Blount		(See above)	
	Pewano		(See above)	

SECTION III
DESIGN METHODOLOGY

Several design alternatives are available for wastewater application to the irrigation sites discussed in the previous section. In this section, design alternatives are presented for wastewater application rates, irrigation methods, underdrain systems, erosion and water runoff control, and site-related facilities such as water transmission methods, buffer strips, reuse storage facilities, and recharge outfalls. Costs for the alternatives are given in Section IV. The selected alternative for several components of the land treatment facility is discussed in Section V. Alternative designs were developed for the southern parts of the St. Clair and Monroe sites. These sites are assumed to represent soil, topography, and other conditions likely encountered for potential irrigation sites. For the purpose of design selections, certain designs and costs were developed for the southern part of St. Clair and Monroe sites. These designs and costs are contained in Appendix A.

WASTEWATER APPLICATION

Several land treatment facilities in the United States operate year-round and/or apply more than two inches of wastewater per week. But, an average wastewater application of two inches per week for 35 weeks (70 inches/year) was selected as being optimum for the Southeastern Michigan Wastewater Management Program.

The average seasonal period for wastewater irrigation is expected to be April through November. The main factors affecting the selection of the rate and duration of wastewater application were soil characteristics, climate, crops to be grown, and the quality of applied wastewater and its desired extent of renovation.

The soils of the wastewater irrigation sites are medium to fine textured, mineral soils with permeability to water exceeding 0.8 inches per hour in the surface soil horizon and a minimum of 0.2 inches per hour in subsurface soil horizons. Soil characteristics were discussed in the previous section and were summarized in Table II-1. These relatively level soils frequently are "wet" with ground water fluctuating from near the surface in the spring down to around 10 feet later in the year. Farmers frequently tile drain these soils to produce agricultural crops. Even where the subsurface soil permeabilities may be as little as 0.2 inches per hour, a functional underdrain system should remove excess soil water rapidly enough to permit two inches of wastewater application in addition to normal rainfall. If abnormally heavy rainfall occurred, lagoon storage could provide temporary delay in wastewater application. Considering only soil permeabilities, more than two inches per week of wastewater can pass through the soil matrix providing reasonable soil infiltration rates, tile drainage rates, and irrigation rates are maintained. Unfortunately, soils within the potential irrigation sites are susceptible to surface slacking which reduces water infiltration rates. Additionally, monovalent

cations (especially Na) contained in the applied wastewater tend to disperse the surface soil, thereby reducing infiltration rate. Such infiltration rate reductions tend to enhance probability of excessive water ponding and water runoff without proper wastewater renovation. Due to the low permeabilities, the soils are expected to be wet much of the year with an annual application of 70 or more inches wastewater. Such wetness could influence crop yields, limit the depth of aerobic soil, and alter soil chemical and physical properties. Considering the above soil characteristics, the average application rate of two inches per week is selected as being the upper limit for the potential irrigation sites under consideration.

The climate of the Southeastern Michigan area has above freezing mean weekly temperatures from about mid-March to the last week of November (81,87). The growing season or average length of the freeze-free period ranges from about 150 to 180 days (22). However, with average daily temperatures and soil temperatures above freezing, the irrigation season could be somewhat longer than the growing season. The normal period without significant snow cover varies from around mid-March or April 1 to about December 1-15. Thus, 35 weeks was selected as the optimum irrigation season.

Crops selected include perennial grasses and legumes. This permits the maximum seasonal use of the "living filter" for wastewater and soil renovation. The perennial crops (particularly grasses) are especially valued to take advantage of early or late season warm periods and to minimize the need for cultivation.

Nitrogen is considered the most limiting wastewater constituent. The nitrogen content of 20 ppm in the wastewater contributes 315 pounds of nitrogen to each acre of soil receiving an average of two inches wastewater per week for 35 weeks. The "living filter" is expected to remove 85% of the nitrogen and 15% would be discharged with the drainage water (82). If the underdrain discharges about 70 inches of water annually (irrigation water plus rainfall less evaportranspiration), then the nitrogen content of the tile drainage water would be approximately 3 ppm (20 ppm x 15%). This just meets the CORPS goals of <4 ppm NO_3-N* and NO_2-N in the renovated wastewater. Perhaps 85% nitrogen removal is ambitious for the Southeastern Michigan Wastewater Management Program if 315 pounds of nitrogen are annually applied. To achieve this nitrogen removal, denitrification must be about 30-50% and crop uptake of nitrogen must annually exceed 100-150 pounds per acre. Thus, 70 inches of annual wastewater application is believed the upper limit for a safe nitrogen loading. Application of more than 70 inches of wastewater results in nitrogen loadings exceeding 315 pounds/acre/year.

The application rate of two inches per week is in agreement with spray irrigation recommendations evolved from the Pennsylvania State University studies (58,59). Soils in these studies have similar textures but perhaps higher permeability rates than soils in the Southeastern Michigan irrigation sites. But, the Penn State irrigation site did not have an underdrain system like that proposed for the Michigan irrigation sites.

*Assumes all nitrogen undergoes nitrification.

IRRIGATION METHODS

Spray irrigation and two other irrigation techniques were examined for wastewater application to lands. Spray irrigation received major attention while other techniques were briefly examined.

Center pivot irrigation rigs with laterals up to 1450 feet long were investigated for providing spray irrigation. These rigs produce rather high water application rates, especially toward the end of the lateral. A fixed set sprinkler system was also investigated as another form of spray irrigation.

Graded border and furrow irrigation were selected as the other techniques for applying the wastewater. Both techniques might be considered a form of overland runoff as defined in the CRREL Report (82), except the percolate is collected in underdrains.

Rapid infiltration was judged unacceptable because of the low permeability of most Southeastern Michigan soils.

For designing and costing purposes, a four square mile module was developed for each irrigation technique. All irrigation equipment, piping, pumping and other requirements were designed and costed for the module. All irrigation techniques were designed to apply a maximum of three inches of wastewater per week. However, wastewater applications are expected to average two inches

per week for 35 weeks. Wastewater irrigation is not expected to be applied during the winter months of December, January, February, and March.

Center Pivot Irrigation System

The center pivot irrigation system is a self-propelled lateral which irrigates a circular area. The sprinkler lateral is supported by wheeled towers and by steel trusses or cables between the towers. The irrigation water comes to the pivot point by underground pressure mains from a central pumping station. Sprinkler size and discharge rates increase from the pivot out to the end of the lateral.

The systems can be powered by water, oil-hydraulic, or electric motors. The electric motor drive with worm gear at the wheel is recommended because of reliability, ease of start-stop control, and low maintenance. Power and control cables will come underground from a central control house to the pivot points.

The wheeled towers are available with steel wheels, rubber tractor tires, and if necessary, low-pressure, high-flotation rubber tires. The rubber tractor tires should be adequate for the sites studied in Southeast Michigan.

The irrigation water can be distributed from the sprinkler lateral by either spray-type nozzles or by rotating impact sprinkler nozzles. The spray-type nozzles are located below the sprinkler lateral and are

pointed downward. This arrangement minimizes aerosol drift, but creates a rather narrow spray pattern (approximately 20 feet). The rotating impact sprinkler nozzles are mounted on top of the sprinkler lateral. This creates greater aerosol drift, but gives a wider spray pattern (approximately 100 feet). The spray or sprinkler nozzles near the end of the lateral can be controlled automatically to shut off when the lateral enters an overlap zone. This will prevent excessive distribution of water in the overlapping zones.

The water application rate (inches/hour) is a function of the system design capacity (inches/week), time allotted for irrigation (hours/week), distance from the pivot, and the width of the spray pattern. Application rate is not a function of the rotational speed of the lateral (revolutions/unit of time). Calculated application rates are shown in Table III-1 for a system designed to apply two inches of water in five days. At a distance of 1300 feet from the pivot, the 20-foot wide spray pattern takes 17.7 minutes to pass across the fixed point on the ground when the rotational speed is 1 rev/120 hours. During this one pass, two inches of water are distributed at an application rate of 6.9 inches/hour. The 100-foot wide spray pattern takes 88.5 minutes to pass across the same fixed point, thus reducing the application rate to 1.4 inches/hour. Changing the rotational speed to 5 rev/120 hours reduces the amount of water applied per revolution, but the time required for the spray patterns to pass a fixed point is reduced in direct proportion; therefore, the application rate is still the same.

TABLE III-1

Application Rates Using Center Pivot Irrigation System for Two Inches of Water Applied in 120 Hours Total Spray Time

Distance From Pivot (Feet)	20' Wide Spray Pattern						100' Wide Spray Pattern					
	5 Rev/120 Hr			1 Rev/120 Hr			5 Rev/120 Hr			1 Rev/120 Hr		
	Duration (Min.)	Application Rate (In./Hr.)	In./Rev.	Duration (Min.)	Application Rate (In./Hr.)	In./Rev.	Duration (Min.)	Application Rate (In./Hr.)	In./Rev	Duration (Min.)	Application Rate (In./Hr.)	In./Rev.
600	7.7	3.1	0.4	38.5	3.1	2.0	38.5	0.6	0.4	192.5	0.6	2.0
900	5.1	4.7	0.4	25.6	4.7	2.0	25.5	0.9	0.4	128.0	0.9	2.0
1300	3.5	6.9	0.4	17.7	6.9	2.0	17.5	1.4	0.4	88.5	1.4	2.0
1450	3.2	7.5	0.4	15.9	7.5	2.0	16.0	1.5	0.4	79.5	1.5	2.0

The application rates produced by the center pivot irrigation system (Table III-1) exceed the published maximum irrigation application rates (45) recommended for the soils at the potential wastewater irrigation sites. The excessive water application could cause soil erosion and surface water runoff. Several factors will minimize, if not completely eliminate, this potential problem. Irrigation periods of short duration (e.g., 3-40 minutes as in Table III-1) should favor higher water infiltration rates for a particular soil. Generally, soils have higher infiltration rates during the first part of the wetting period (Figure III-1). Thus, irrigation periods of short duration should reduce soil erosion and water runoff because of the higher infiltration rates. Also, a cover crop improves the infiltration rates and minimizes soil erosion.

Should the preceding factors not minimize the application rate problem, excessive water runoff can be prevented by forming land cells (Figure III-2) on the soil surface. These cells capture potential runoff water and cause the water to infiltrate the soil surface. Water may be ponded for a short time in the land cells.

Three different module designs were developed for this study by varying the coverage of the four square mile module with irrigation rigs. These designs are designated Center Pivot Irrigation - 76% coverage, - 91% coverage, and - 95% coverage and are shown in Figures III-3, III-4, and III-5, respectively. Land coverage within a module was computed by:

$$\frac{\text{(Land Area/Irrigation Rig)} \times \text{(Number of Rigs/Module)}}{\text{Land Area/Module}} \times 100 = \text{\% coverage}$$

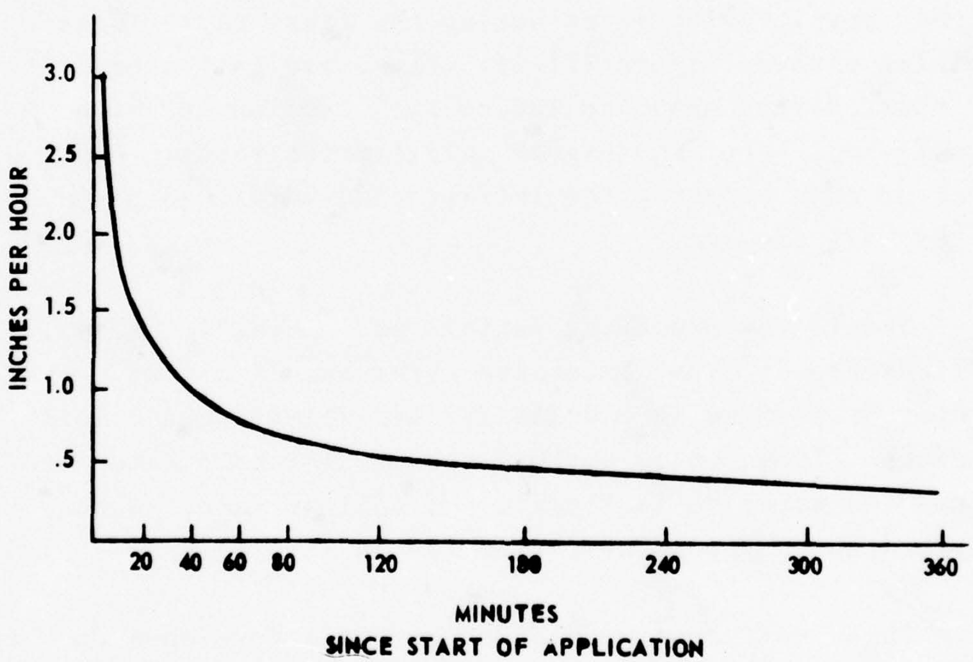


Figure III-1

Generalized Curve Showing Variation in Infiltration Rates with Time

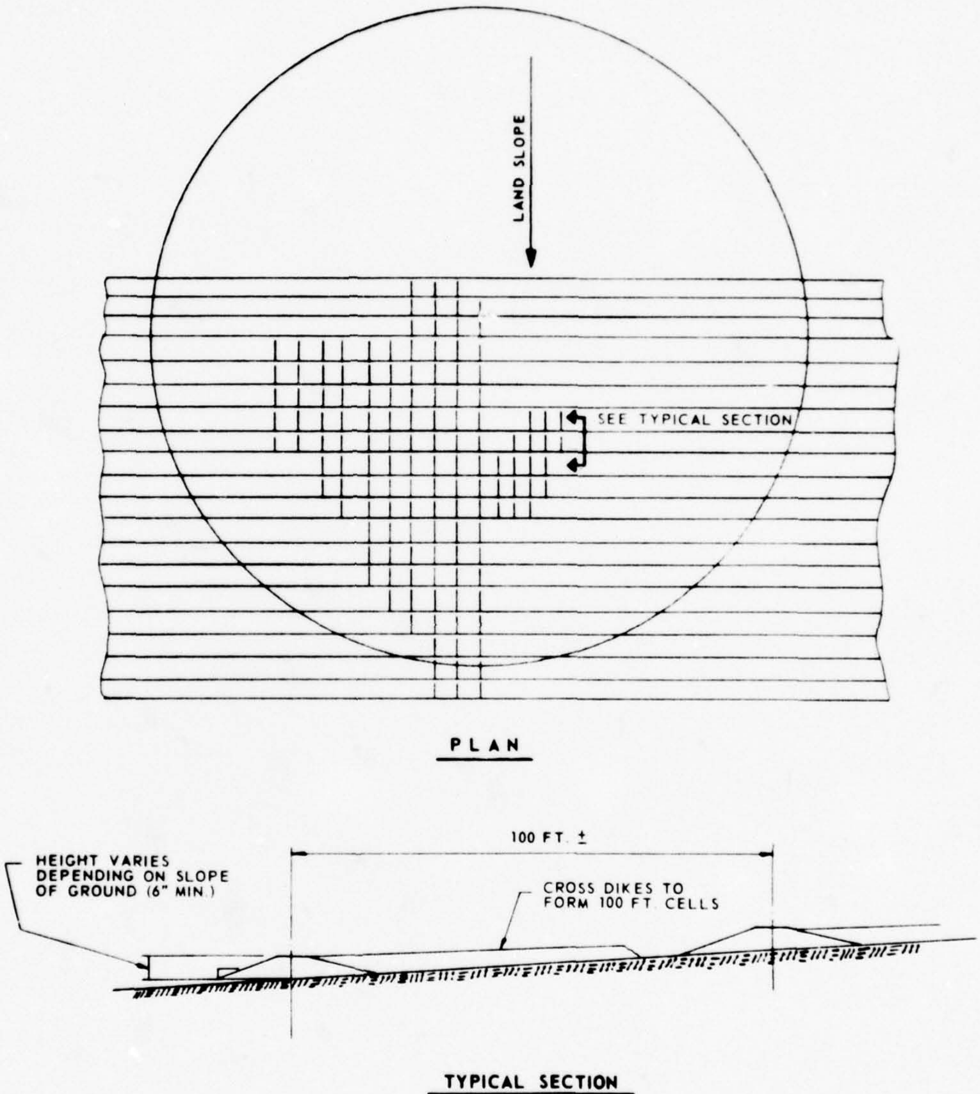
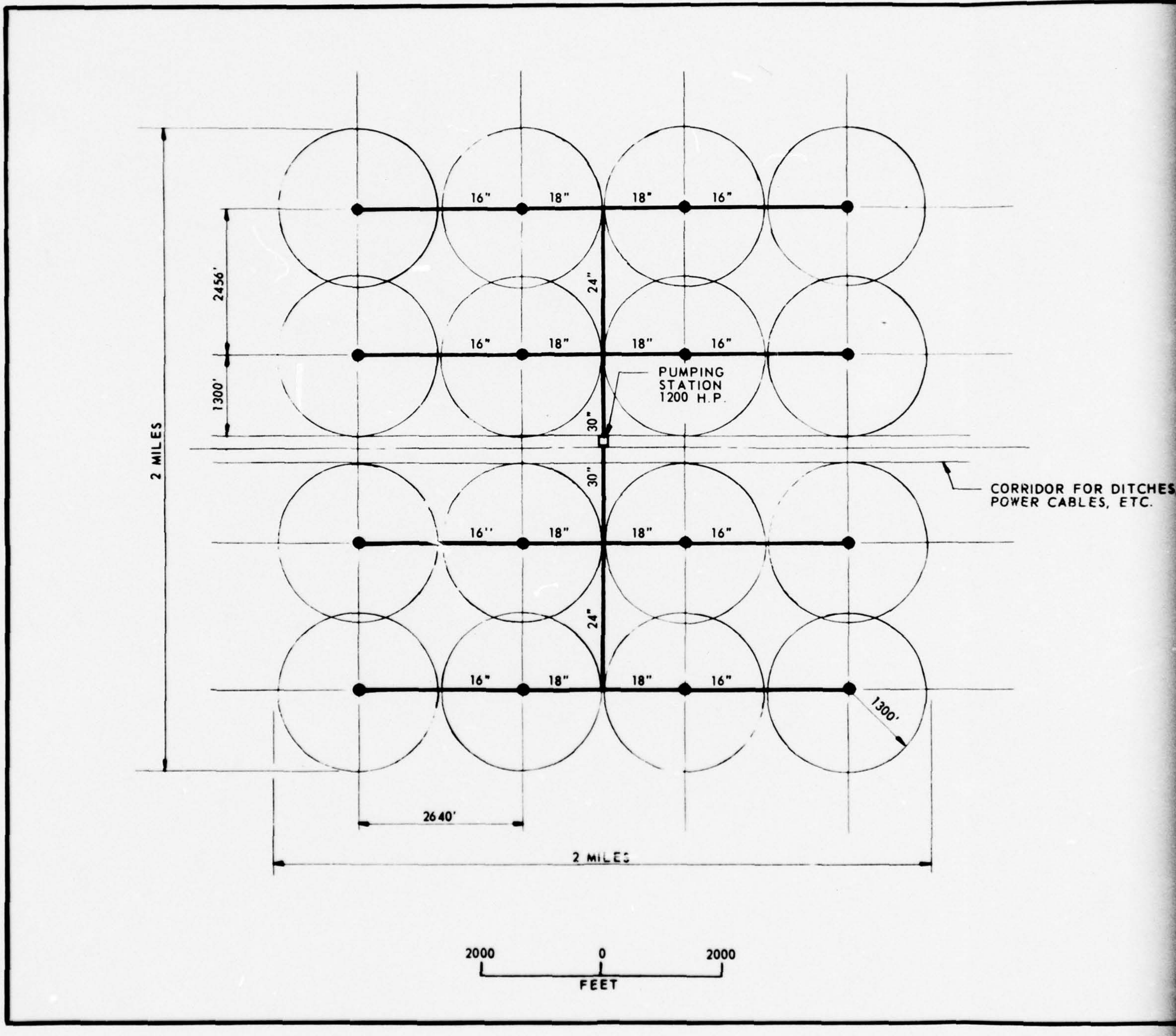
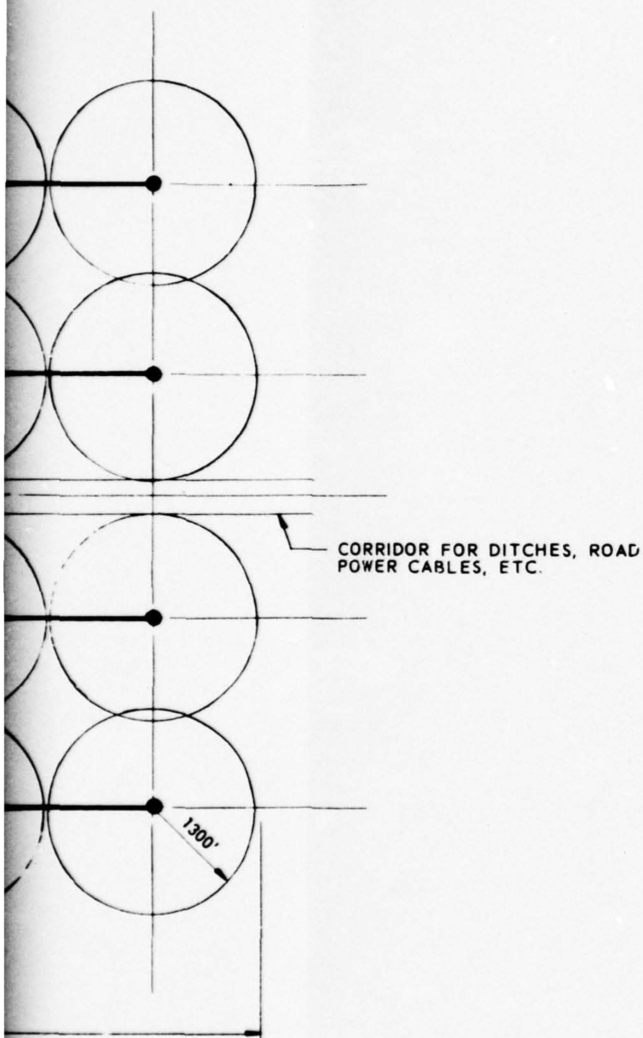


Figure III-2
Land Cells for Center Pivot
Spray Irrigation



16"
18"
18"
16"
24"
2456'
1300'
PUMPING
STATION
1200 H.P.
30"
2 MILES
CORRIDOR FOR DITCHES,
POWER CABLES, ETC.
1300'
2640'
2 MILES
2000
0
2000
FEET

1

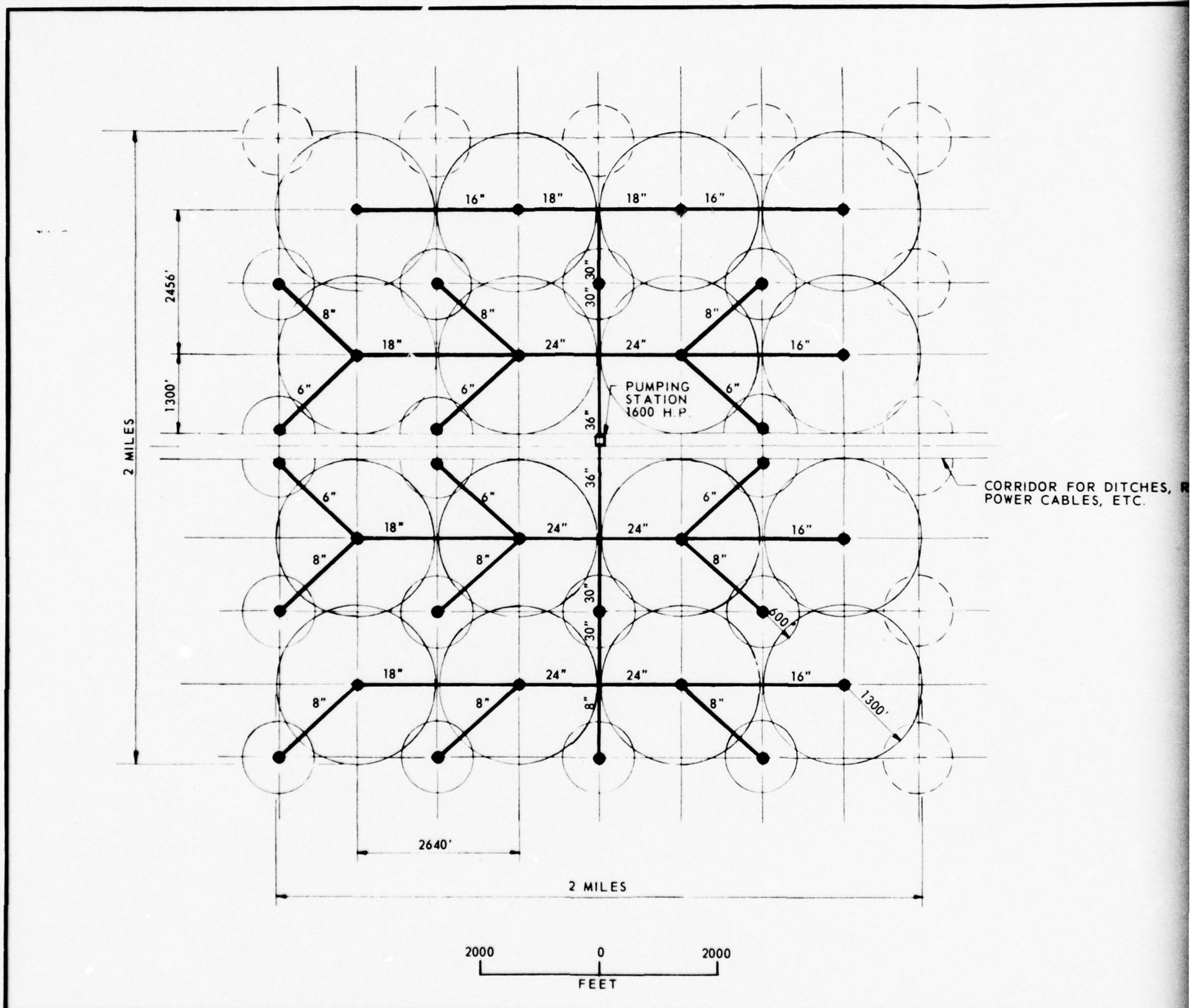


PIPE	QUANTITY
16" CA	22,400 LIN. FT.
18" CA	11,200 LIN. FT.
24" STEEL	5,200 LIN. FT.
30" STEEL	3,000 LIN. FT.

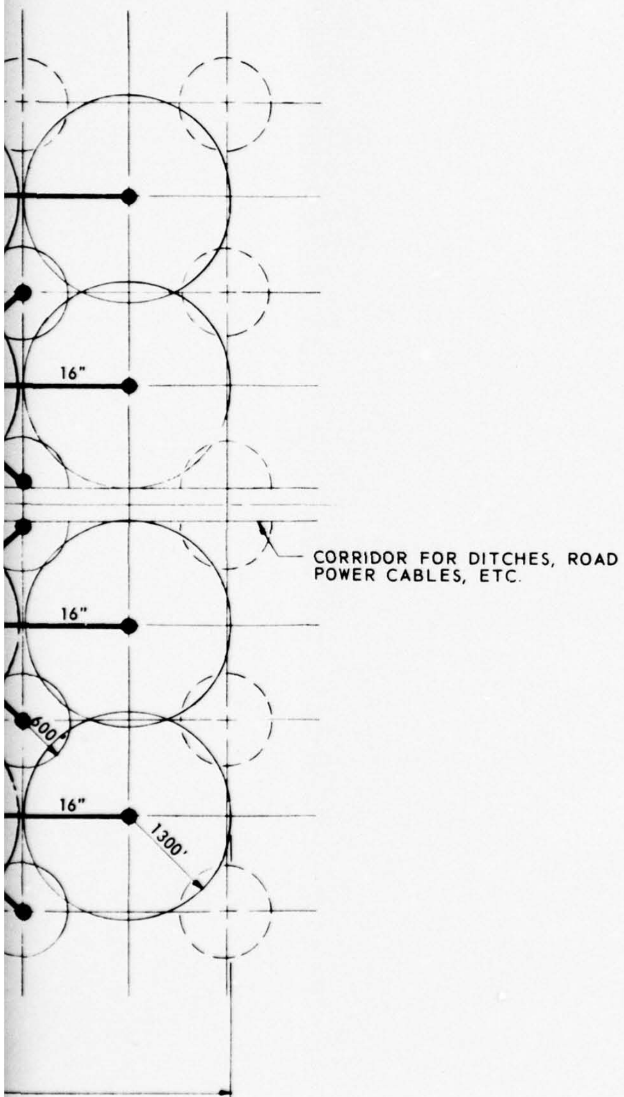
Figure III-3

Design Module for Center Pivot Irrigation Rigs Giving 76% Land Coverage

2


16"
18"
30"
2456'
1300'
8"
6"
24"
PUMPING
STATION
1600 H.P.
36"
2 MILES
CORRIDOR FOR DITCHES, R
POWER CABLES, ETC.
600'
1300'
2640'
2 MILES
2000
0
2000
FEET

1

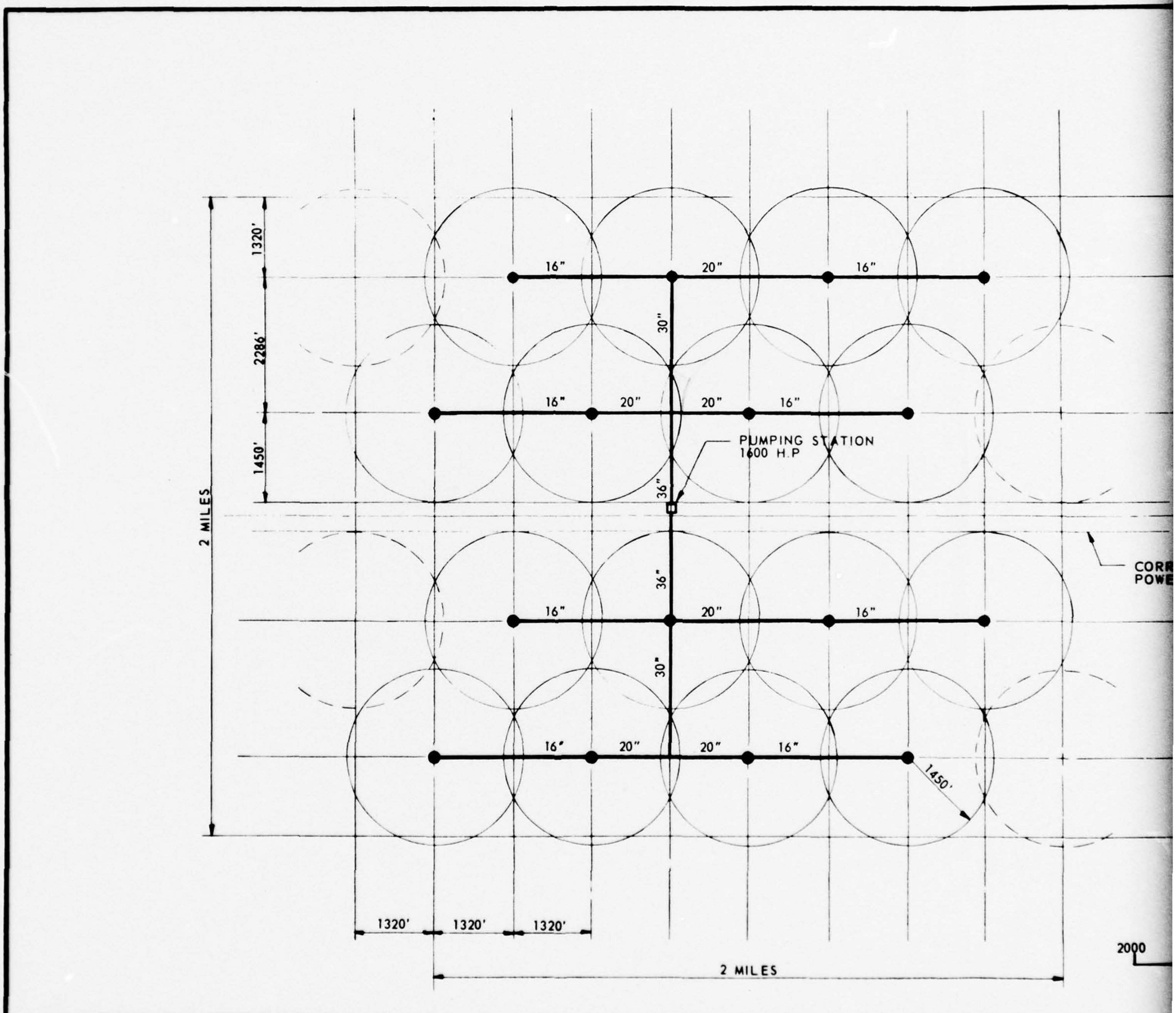


PIPE	QUANTITY
6" CA	12,000 LIN. FT.
8" CA	19,200 LIN. FT.
16" CA	14,000 LIN. FT.
18" CA	11,200 LIN. FT.
24" STEEL	8,400 LIN. FT.
30" STEEL	5,200 LIN. FT.
36" STEEL	3,000 LIN. FT.

Figure III-4

Design Module for Center Pivot Irrigation Rigs Giving 91% Land Coverage

2



1320'
2286'
1450'
2 MILES
16"
20"
16"
30"
16"
20"
20"
16"
PUMPING STATION
1600 H.P
36"
36"
CORR
POWE
16"
20"
16"
30"
16"
20"
20"
16"
1450'
1320'
1320'
1320'
2 MILES
2000

PIPE	QUANTITY
16" CA	21,000 LIN. FT.
20" CA	10,400 LIN. FT.
30" STEEL	5,000 LIN. FT.
36" STEEL	4,000 LIN. FT.

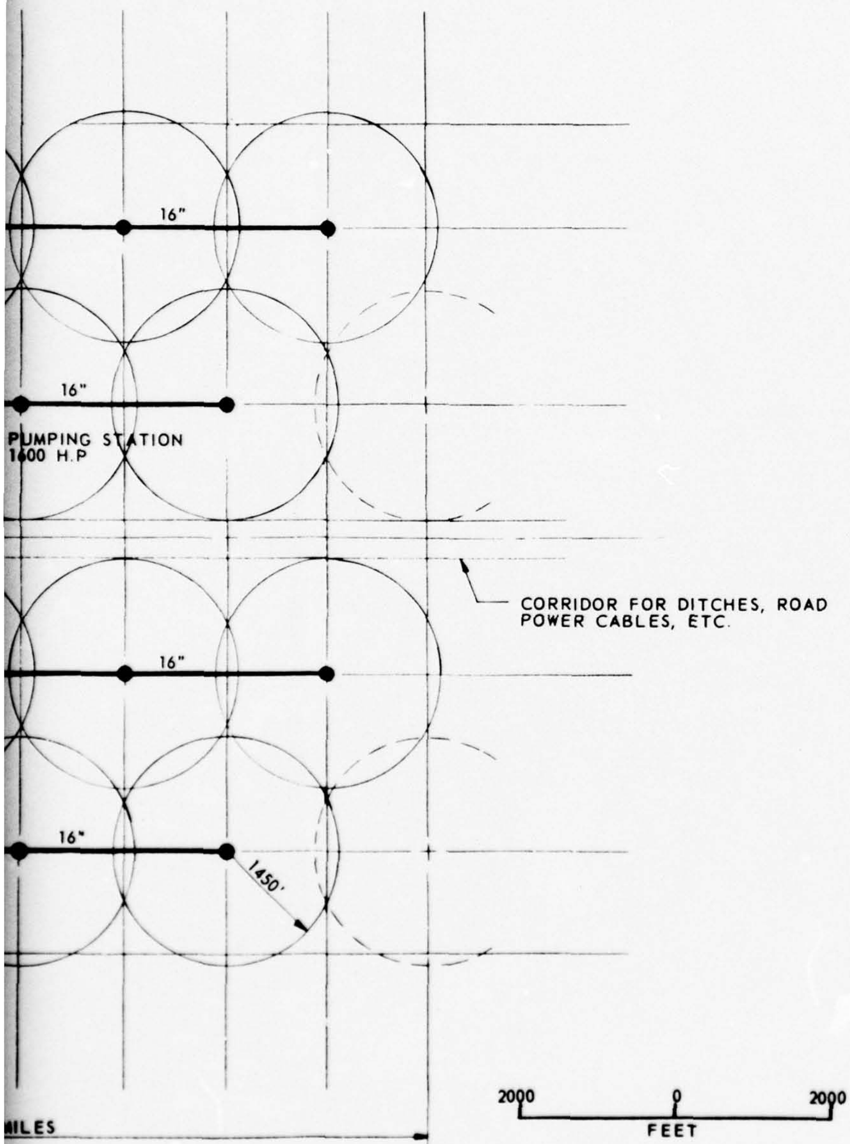


Figure III-5

Design Module for Center Pivot Irrigation Rigs Giving 95% Land Coverage

2

The 76% coverage has the least overlap; whereas, the 95% coverage has the greatest overlap. The 91% coverage module utilizes more than twice the number of irrigation rigs as the other two modules.

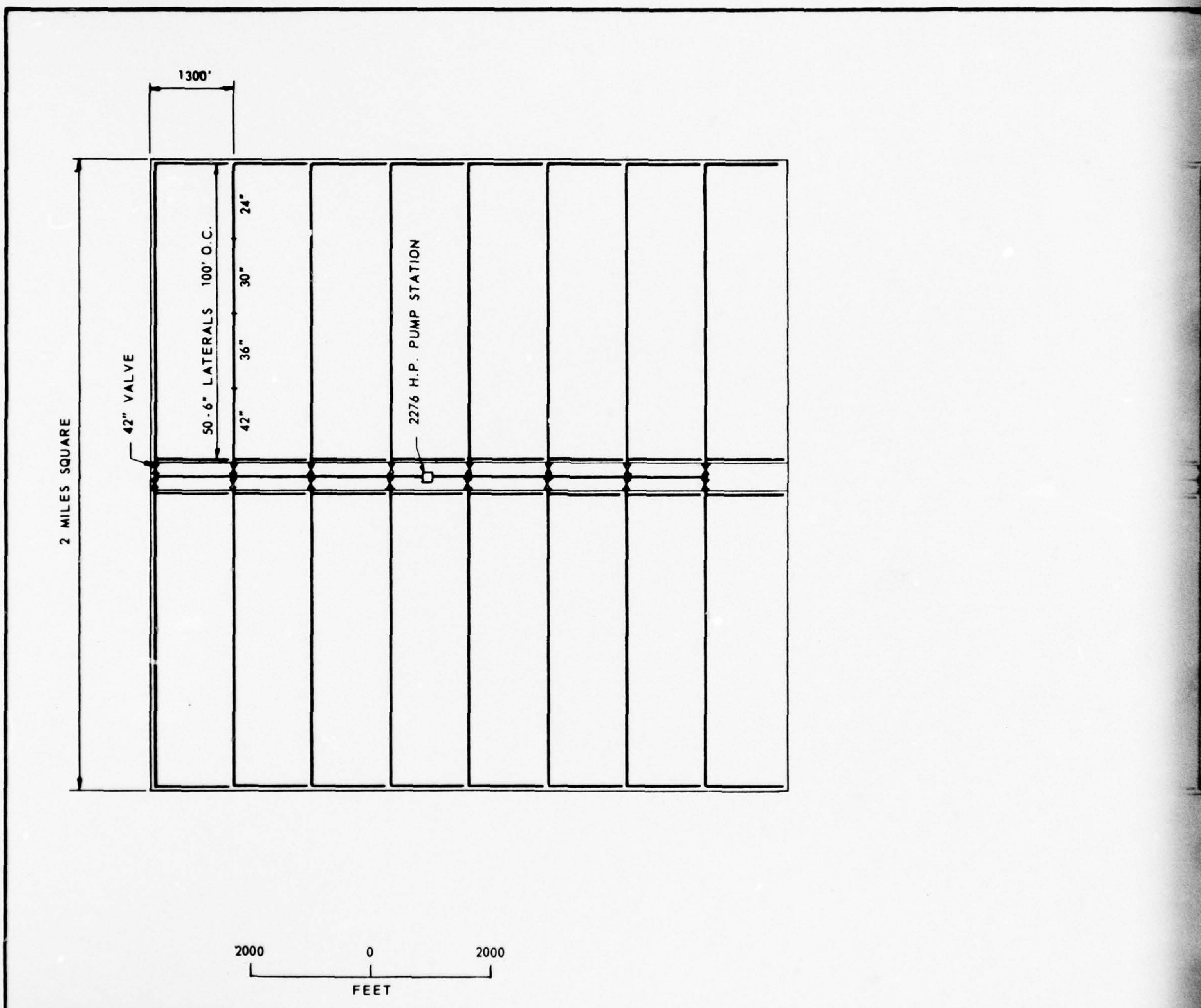
Fixed Set Spray Irrigation

A fixed set sprinkler system was investigated as another form of spray irrigation. This investigation was conducted to provide an alternate spray irrigation system to the center pivot rigs and their associated high water application rates.

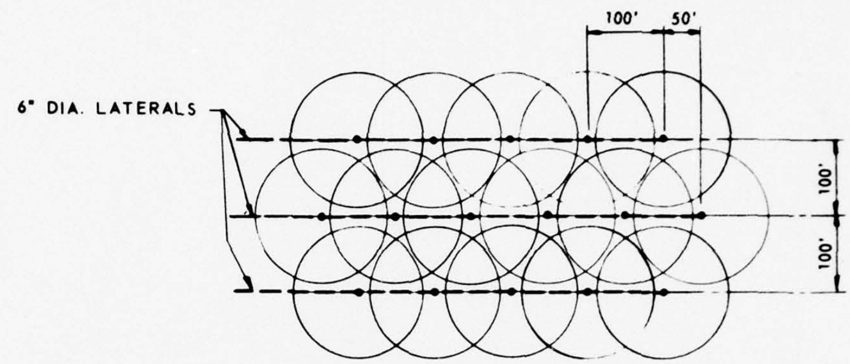
The fixed set system consists of permanent underground pipes delivering water to risers containing spray nozzles. The system was designed with an 0.37 inch/hr. application rate. Each nozzle sprays a radius of about 170 feet. Laterals are spaced at 100 feet to provide the necessary spray overlap for uniform water coverage. The design for the fixed set system is contained in Figure III-6. The module is divided into 16 zones operating individually off the central pressure main. Each zone will operate for approximately 5.5 hours to apply two inches of water. A total irrigation time of 87 hours/week is required to cover the entire module. Eight hours per zone and 130 hours/week are required to apply three inches of water per week. The nominal line pressure required at the nozzles is 70 psi.

Graded Border and Furrow Irrigation

Graded border and furrow irrigation methods were examined to provide alternates to spray irrigation.



1300'
2 MILES SQUARE
42" VALVE
50-6" LATERALS 100' O.C.
42"
36"
30"
24"
2276 H.P. PUMP STATION
2000
0
2000
FEET



SPRINKLER OVER LAP PATTERN

6" DIA. LATERALS	1,040,000'
24" DIA. STEEL PIPE C.&W.	21,120'
30" DIA. STEEL PIPE C.&W.	21,120'
36" DIA. STEEL PIPE C.&W.	21,120'
42" DIA. STEEL PIPE C.&W.	25,940'
42" MOTOR OPERATED VALVE	16
1 PUMP STATION	2276 H.P.
SPRAY HEADS	10,400

Figure III-6
Design Module for Fixed Set Spray Irrigation

2

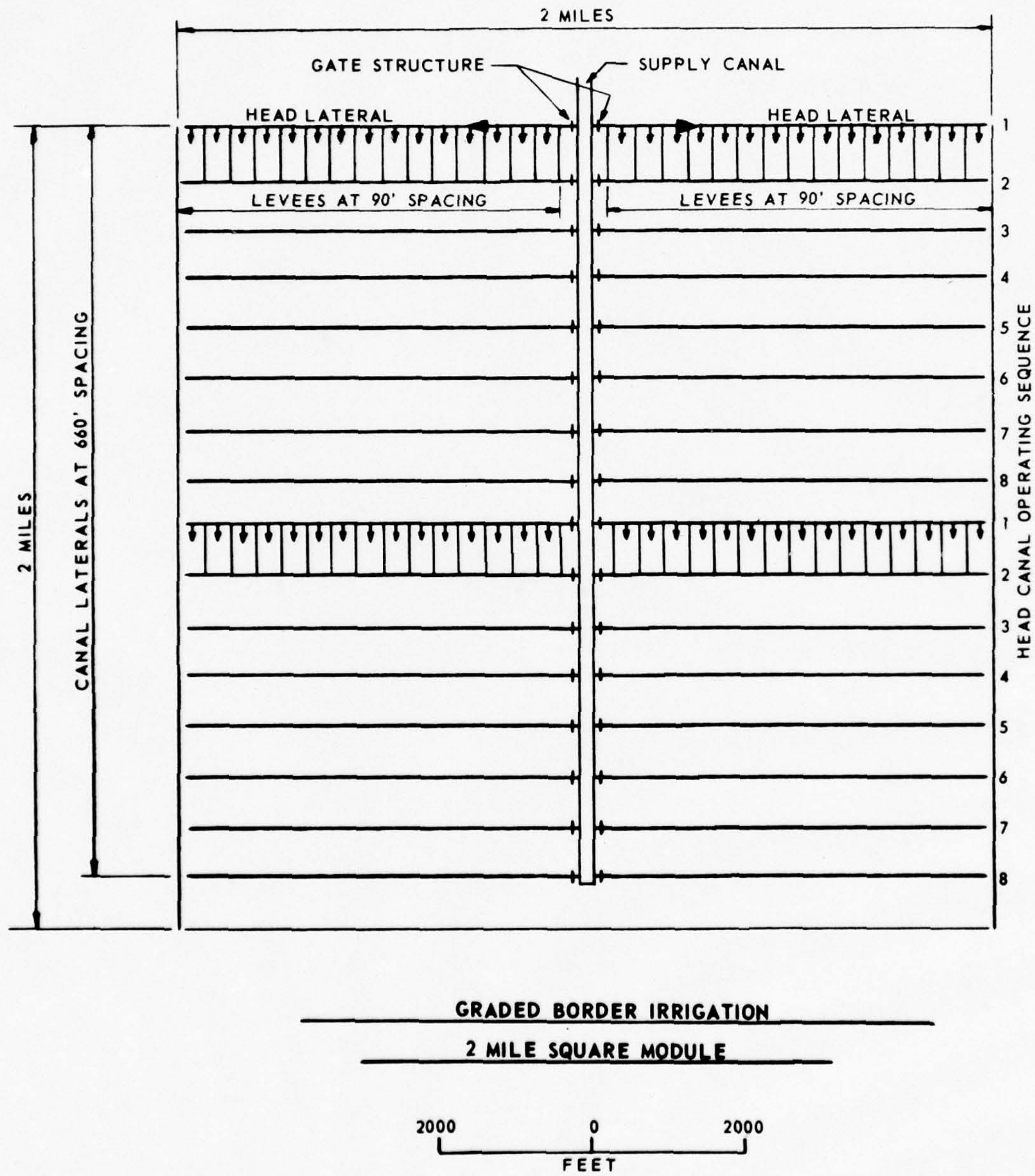
These methods show promise for the potential wastewater irrigation sites primarily because surface soils in Southeastern Michigan have rather low permeability rates.

Graded border irrigation (Figure III-7) is a method of applying water to land between parallel ridges or borders. The strips of land between adjacent borders have little or no cross slope, but have a grade in the direction of irrigation. The parallel ridges are usually called levees. The strips of land between the levees are usually called strip checks.

The irrigation water is applied to the upper end of the strip checks from either open ditches or low pressure underground pipes. The water travels by sheet flow over the strips until infiltrating the soil surface.

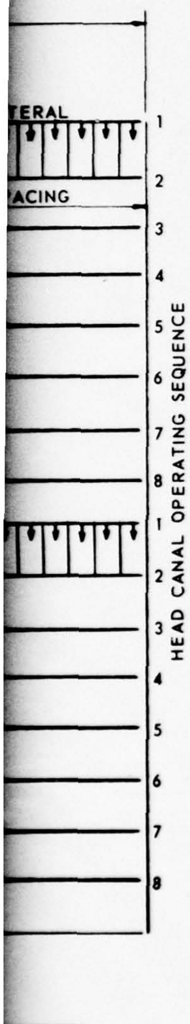
The graded border method has traditionally required much labor effort to apply and control the application of the water. The water was applied by cutting notches in dirt head ditches, installing individual siphon tubes, opening wooden check gates, and installing temporary check dams. Considerable effort in the past few years has been expended to develop automated water application systems. The most success has been with systems that use low pressure buried pipelines with controlled outlets located along the upper end of the strip checks. These systems use standpipes to provide the head and pneumatic cutoff valves to control the outlets.

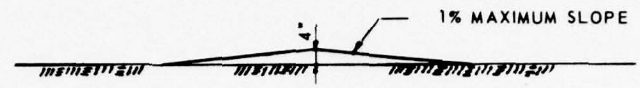
Another rather recent development is the return water system used with the graded border method. The



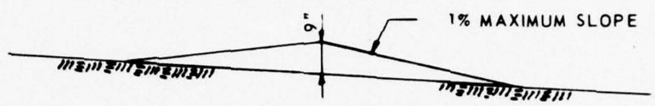
GRADED BORDER IRRIGATION

2 MILE SQUARE MODULE

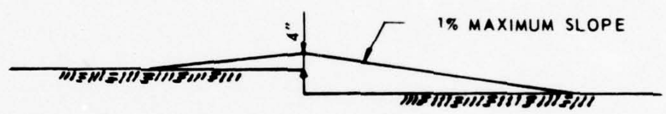




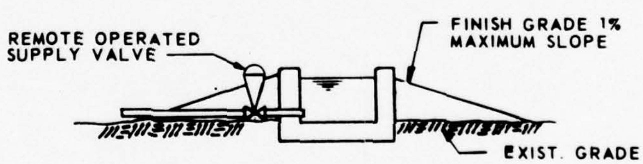
LEVEE SEPARATING STRIPS HAVING 0% CROSS SLOPE



LEVEE SEPARATING STRIPS HAVING MAXIMUM OF 0.1% CROSS SLOPE



LEVEE SEPARATING STRIPS HAVING 0% CROSS SLOPE AT DIFFERENT ELEVATIONS



SECTION THROUGH HEAD LATERAL

Figure III-7

Design Module for Graded Border Irrigation

2

water application rate and slope of the strip are selected so that excess water reaches the end of the strip check. It is collected in a sump and pumped back to the head of the strip. This assures all of the strip is irrigated and the water is applied more uniformly along the length of the strip. This system is desirable where the supply of irrigation water is limited or its cost is high.

For this study a combination of these various water control techniques were designed and costed. The head laterals are designed as open concrete channels with valved pipes delivering the irrigation water to the upper end of the check strips. The valves will be remotely controlled by timers that are set to supply the required amount of water to the head of a check strip.

Four of the head laterals will be in operation at the same time for a period of approximately 15 hours. With a total of 32 laterals per module it will require 120 hours per week to complete the irrigation of a module.

The head laterals are designed to supply a maximum of three inches of irrigation water per week. The normal application rate of two inches per week is achieved by varying the number of valved pipes that are operating during an irrigation cycle.

Furrow irrigation is very similar to the border method except the water travels in furrows graded down the slope and the dividing levees are not needed. The furrows are about 40-42 inches apart. The irrigation

water is directed to the head of each furrow by a gated pipe that is attached to the supply pipe from the head lateral. The gates are located on the same spacing as the furrows.

GROUNDWATER CONTROL

A groundwater control system is necessary to provide the aerobic soil zone needed for proper renovative action of the soil. The control system should also prevent irrigation groundwater loss from the site by collecting the percolate and directing it to controlled discharge points.

A perforated tile underdrain system was selected as the method for collecting the percolated water. The system consists of parallel perforated tile laterals which tie into submains. The collected percolate flows through submains and mains to a low-head pump station located on the lower edge of the drainage module. The pump lifts the percolate into open canals which direct the percolate to the reuse storage facilities.

Present agricultural drainage practices (70) of three to four foot depth to the drain and spacings up to 100 feet will not meet the requirements of the land treatment concept.

A ditch along the perimeter of the land treatment site is also considered for additional groundwater control. This ditch, cut to a depth lower than the tile

drains, would intercept any lateral movement of groundwater away from the irrigation sites. This water would be tested and if it does not meet the required quality, it would be returned to the incoming irrigation water stream. Normally, this water would be expected to meet the desired quality standards and it would be added to the outgoing renovated water canals.

Observation wells are planned for monitoring the deeper groundwater zones along the perimeter of the land treatment sites. The wells will be located in groups of three, cased and sealed so that three different levels of groundwater can be sampled and tested. For planning purposes, these groups are spaced approximately three miles apart around the land treatment sites.

Tile Underdrain

Design of the tile system was based upon the following requirements:

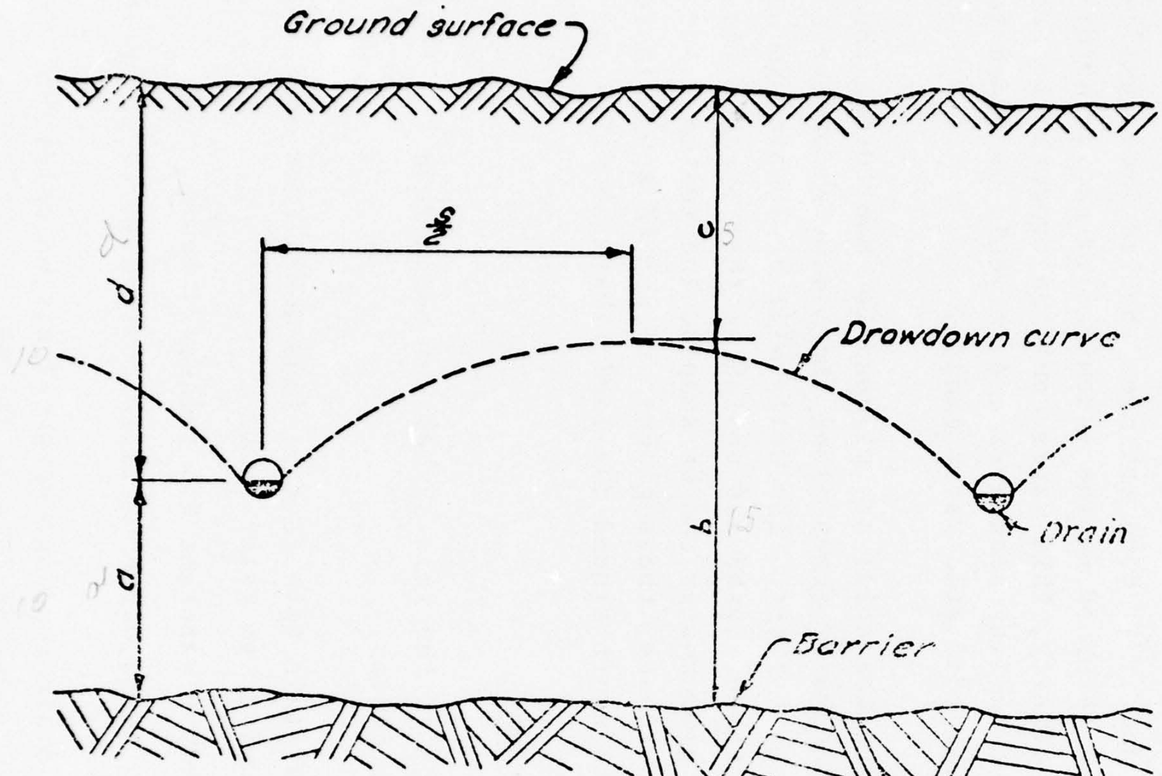
-- maintain five feet minimum depth from soil surface to water table

-- remove water at 0.5 inches/24 hours

-- maintain depth of tile laterals to 10 ft or less.

Tile drain spacings were calculated using the Donnan (73) equation (Figure III-8):

$$S = \sqrt{\frac{4\ P\ (b^2 - a^2)}{Q_d}}$$



Note: If impervious barrier does not exist, assume a = d

Figure III-8. Nomenclature Used in Donnan Equation (60)

where:

S = drain spacing in feet

P = soil permeability (inches/hour). Use permeability of horizon in which drain is located unless horizon above has lower permeability.

Q_d = desired rate of drainage (inches/hour)

a = distance from drain to barrier (feet)

b = distance from drawdown curve to barrier at midpoint between drains (feet)

c = depth to water table at midpoint between drains (feet)

Impervious Barrier

If the water table is below the installed tile drains on a particular land treatment site, a portion of the applied wastewater could pass between the tile drains and enter the groundwater. Hence, an impervious barrier was considered for insuring that all applied wastewater is collected in the tile drains. The impervious barrier is installed slightly beneath the tile drains. An asphalt barrier appears optimum for providing this additional groundwater control. Other known barriers are more costly and/or fail to perform adequately.

The concept requires that a wedge-shaped horizontal plow bar be pulled through the soil at the desired barrier depth. This plow bar creates a temporary cavity in the soil. Fan type nozzles on the back of the plow bar spray hot asphalt into the cavity forming a continuous asphalt barrier. Subsequent parallel strips are placed in an overlapping pattern which forms an impervious barrier.

The asphalt barrier is an extrapolation from an existing commercially available system (2) that has been successfully installed to a depth of 2.5 feet in a sandy soil. The equipment to place the asphalt barrier at the depth required by this project does not exist, but such equipment is believed to be technically feasible.

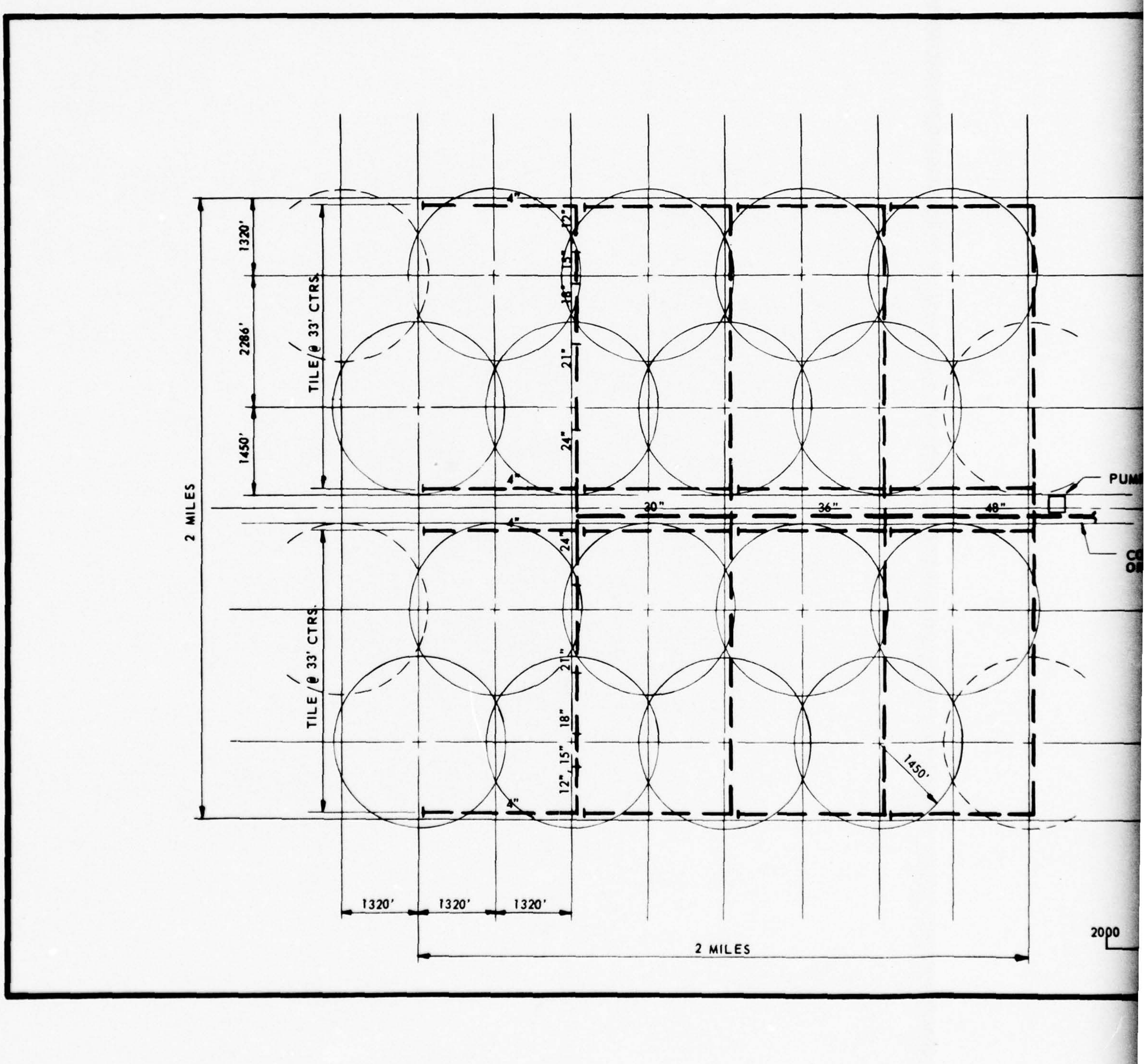
Modular Design

A four square mile module was developed for each underdrain system. The module, same size as an irrigation module, facilitated developing designs and costs.

Three separate drainage module designs were developed. Two of the designs are based on the assumption that the water table will be at or above the installed depth of the tile underdrain because of a naturally occurring impervious barrier. The third design assumes that an artificial barrier must be installed below the depth of the tile drain.

The first design assumes a soil permeability of 0.2 inches/hour and a desired drainage rate of 0.02 inches per hour. The resulting tile lateral spacing was approximately 33 feet on centers (Figure III-9). The 0.2 inches per hour permeability is the lowest found in the soil profile.

The second design assumes a soil permeability of 0.5 inches/hour and the same desired drainage rate.



2 MILES
1320'
2286'
1450'
TILE/@ 33' CTRS.
TILE/@ 33' CTRS.
4"
12"
15"
18"
21"
24"
30"
36"
48"
1450'
1320'
1320'
1320'
2 MILES
2000

PIPE	QUANTITY
4" PLASTIC	3,163,000 L.F./2 MI. SQ.
12" CONC.	6,000 L.F./2 MI. SQ.
15" CONC.	4,560 L.F./2 MI. SQ.
18" CONC.	8,400 L.F./2 MI. SQ.
21" CONC.	12,000 L.F./2 MI. SQ.
24" CONC.	10,650 L.F./2 MI. SQ.
30" CONC.	2,640 L.F./2 MI. SQ.
36" CONC.	2,640 L.F./2 MI. SQ.
48" CONC.	2,640 L.F./2 MI. SQ.
1 PUMP STATION	160 H.P.

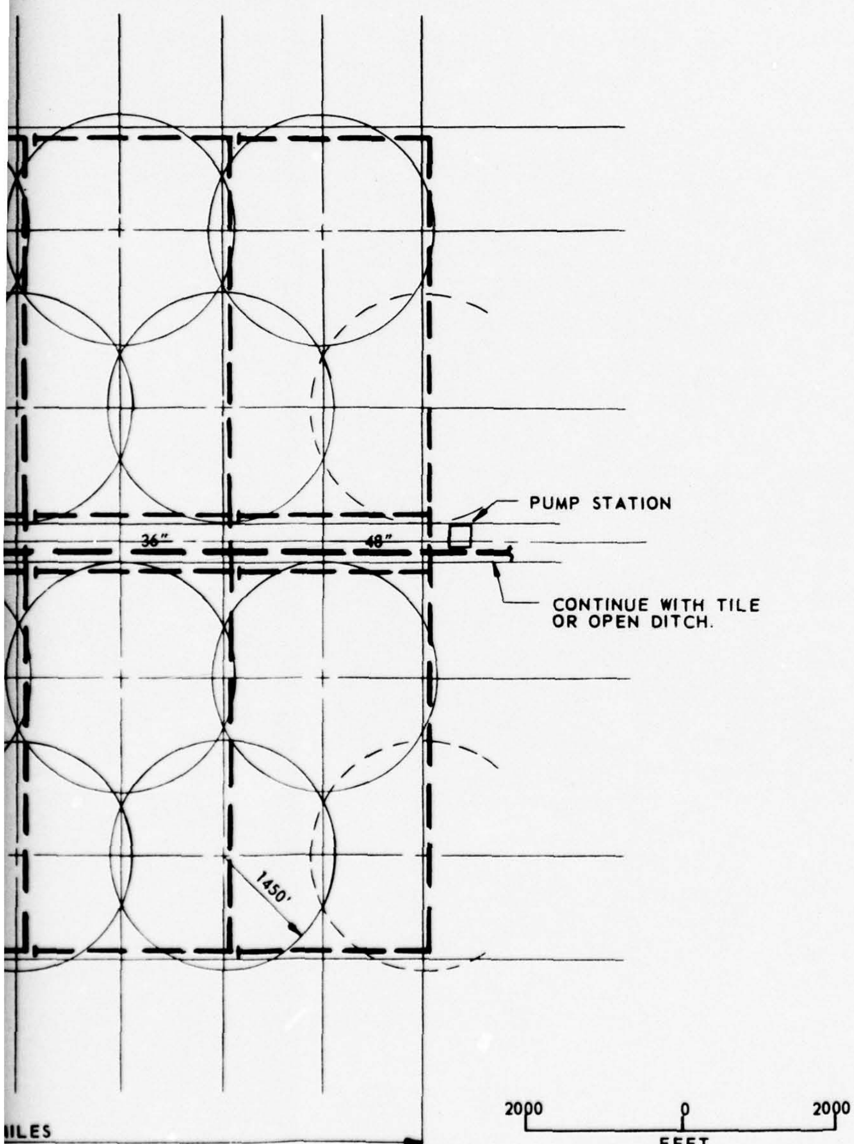


Figure III-9

Design Module for Underdrain System with Tile Laterals Spaced at 33' Centers

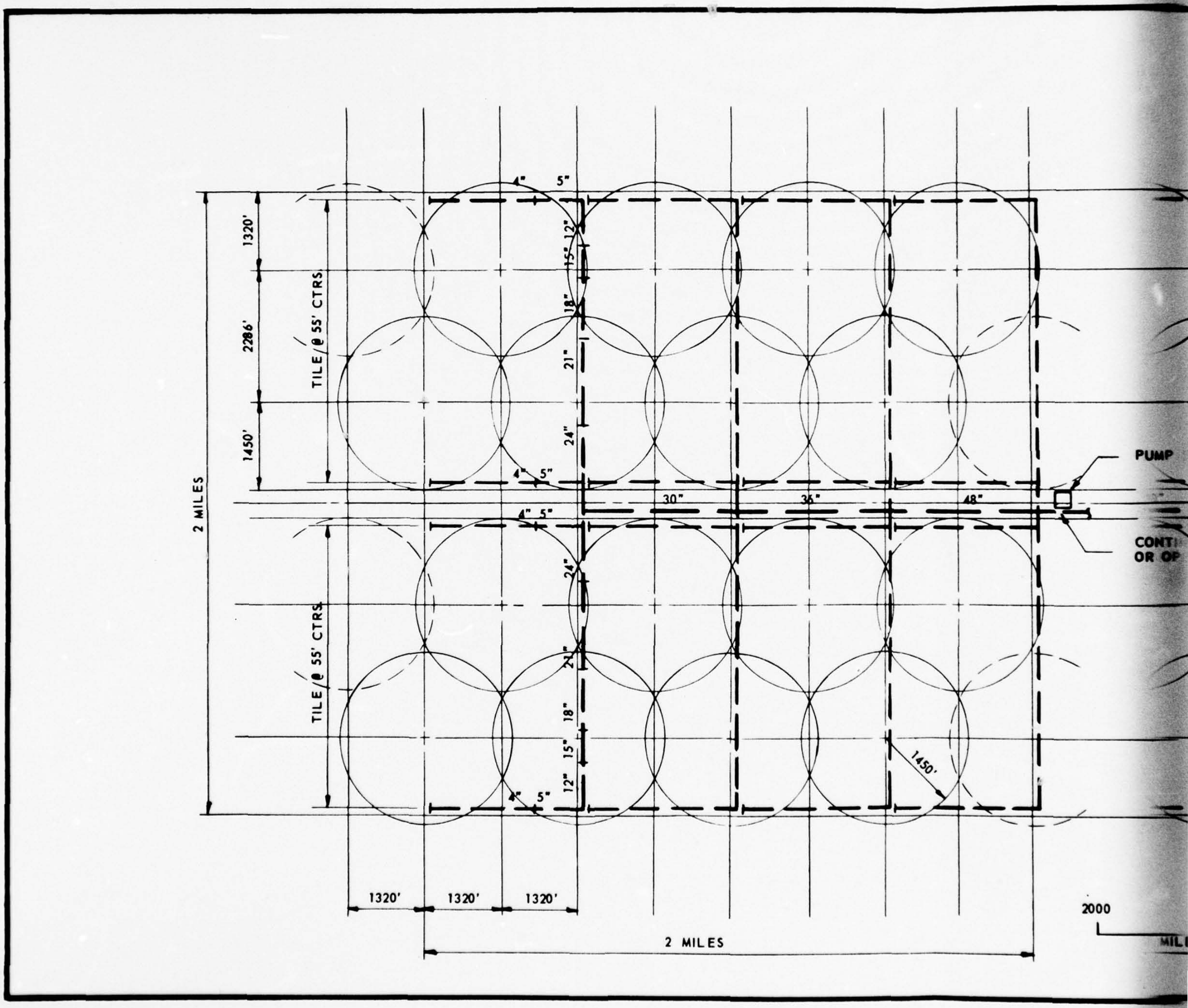
This design resulted in a tile lateral spacing of approximately 55 feet (Figure III-10). The 0.5 inches/hour permeability may be maintainable if a good drainage system is once installed and becomes operational.

The third design assumes a soil permeability of 0.02 inches/hour, and an impervious asphaltic barrier installed approximately one foot below the tiles. This design results in a tile lateral spacing of approximately 16.5 feet (Figure III-11).

SOIL EROSION AND WATER RUNOFF CONTROL

A premise of the land treatment concept is that all secondary treatment effluent that enters the treatment site must pass through the "living filter" and that all waters, including natural rainfall, must pass through controlled and monitored outfalls before being discharged to public waters. Hence, soil erosion and water runoff control must be practiced.

Within the treatment site, the degree of erosion control depends on the irrigation method. Land cells (Figure III-2) previously mentioned in connection with center pivot irrigation systems will provide adequate erosion and water runoff control. If land cells are not used, traditional soil conservation practices such as terraces, diversion berms, ground cover, etc., will be used with the center pivot and the fixed set irrigation systems. Graded border and furrow irrigation systems do not require additional berms, ditches, etc. for erosion control.



4"
5"
1320'
2286'
1450'
TILE/@ 55' CTRS.
12"
15"
18"
21"
24"
30"
36"
48"
PUMP
CONT
OR OP
2 MILES
TILE/@ 55' CTRS.
1450'
1320'
1320'
1320'
2 MILES
2000
MIL

PIPE	QUANTITY
4" PLASTIC	1,324,000 L.F./2 MI. SQ.
5" PLASTIC	590,000 L.F./2 MI. SQ.
12" CONC.	6,000 L.F./2 MI. SQ.
15" CONC.	4,560 L.F./2 MI. SQ.
18" CONC.	8,400 L.F./2 MI. SQ.
21" CONC.	12,000 L.F./2 MI. SQ.
24" CONC.	10,650 L.F./2 MI. SQ.
30" CONC.	2,640 L.F./2 MI. SQ.
36" CONC.	2,640 L.F./2 MI. SQ.
48" CONC.	2,640 L.F./2 MI. SQ.
1 PUMP STATION	160 H.P.

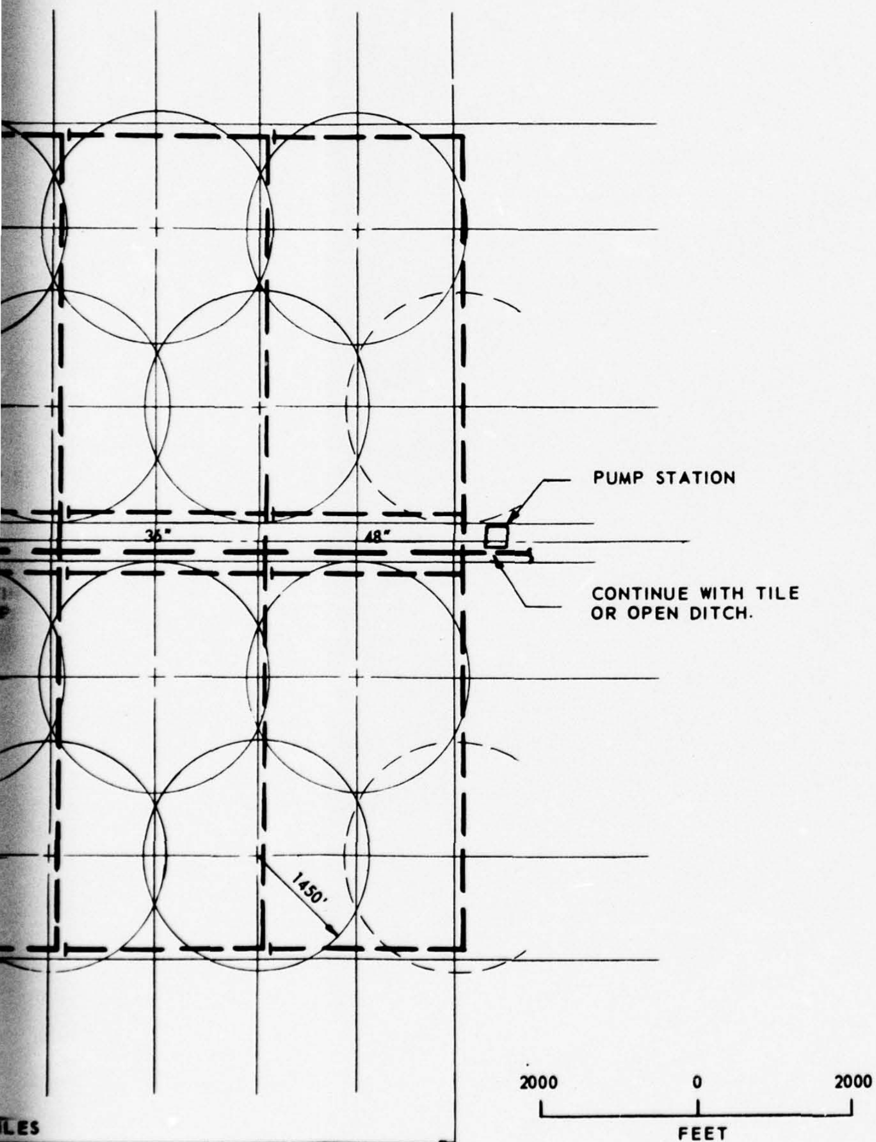
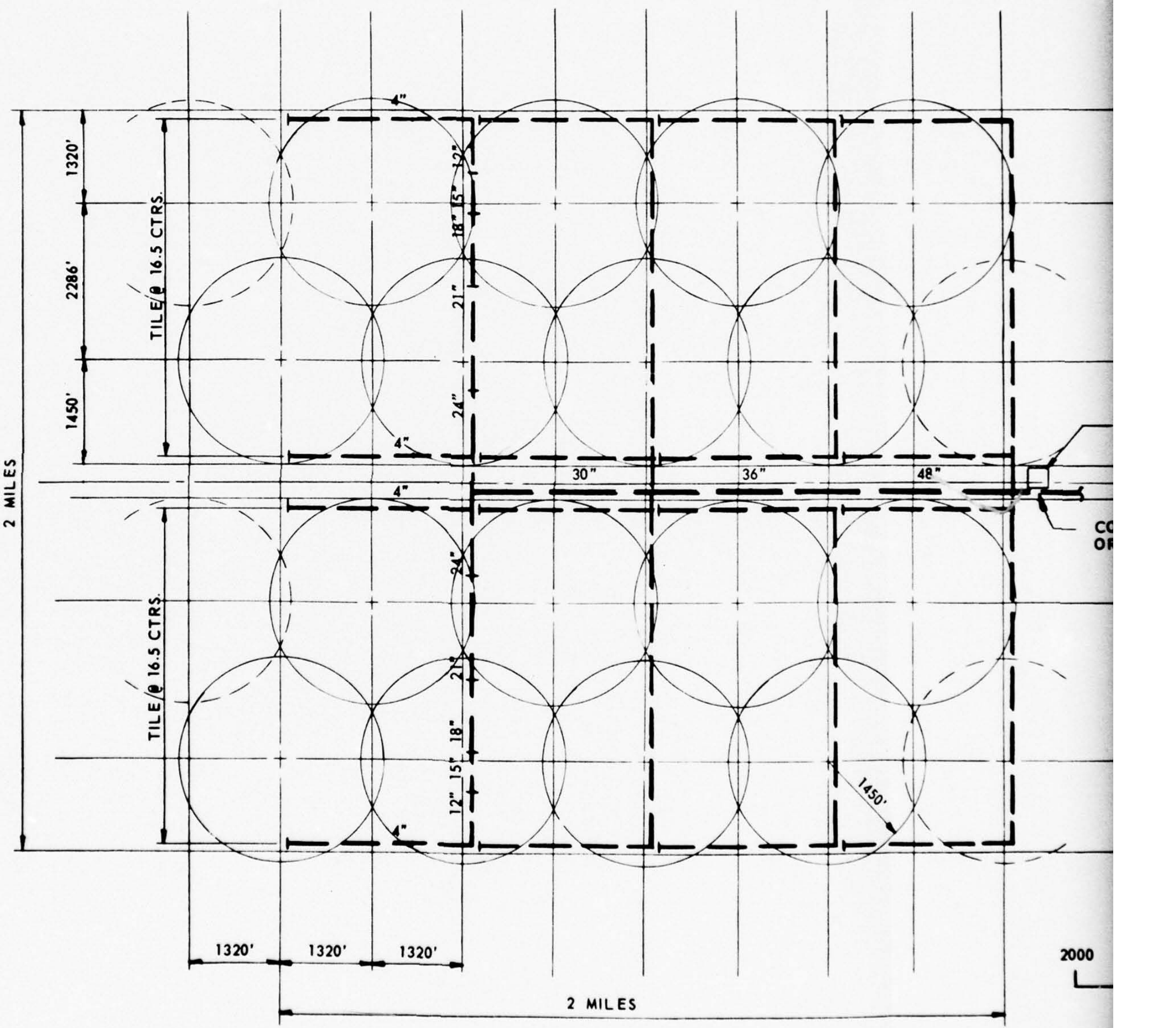


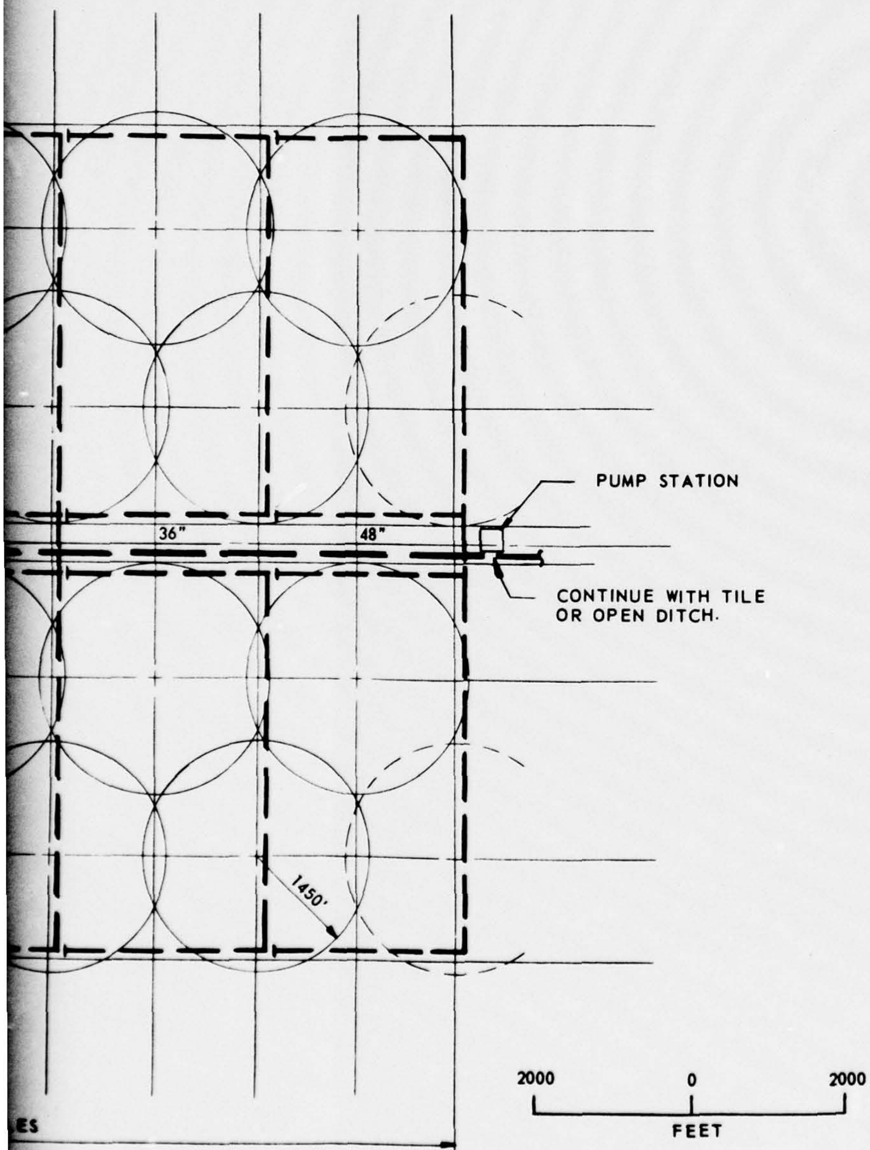
Figure III-10

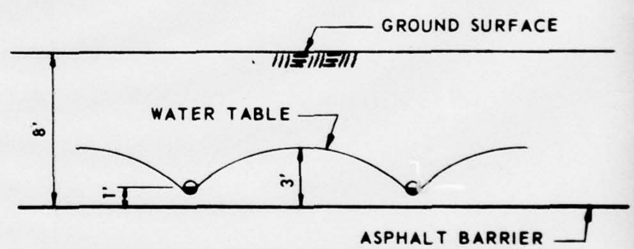
Design Module for Underdrain System with Tile Laterals Spaced at 55' Centers



2 MILES
1320'
2286'
1450'
TILE/@ 16.5 CTRS.
TILE/@ 16.5 CTRS.
4"
4"
4"
4"
12"
15"
18"
21"
24"
24"
21"
18"
15"
12"
30"
36"
48"
1450'
1320'
1320'
1320'
2 MILES
2000

PIPE	QUANTITY
4" PLASTIC	6,324,000 L.F./2 MI. SQ.
12" CONC.	6,000 L.F./2 MI. SQ.
15" CONC.	4,560 L.F./2 MI. SQ.
18" CONC.	8,400 L.F./2 MI. SQ.
21" CONC.	12,000 L.F./2 MI. SQ.
24" CONC.	10,650 L.F./2 MI. SQ.
30" CONC.	2,640 L.F./2 MI. SQ.
36" CONC.	2,640 L.F./2 MI. SQ.
48" CONC.	2,640 L.F./2 MI. SQ.
1 PUMP STATION	160 H.P.
ASPHALT BARRIER	2,500 AC.





TYPICAL SECTION

Figure III-11

Design Module for Underdrain System with Laterals Spaced at 16.5' Centers and with Underground Asphalt Barrier

Some areas within the treatment site will not receive wastewater. Such areas include buffer strips, administrative and services facilities, and border areas around storage facilities. The natural rainfall runoff from these areas will be controlled and routed to the main collected percolate pump station. From this point, the water will pass through the reuse facility along with the collected percolate.

SITE RELATED FACILITIES

Irrigation and drainage modules are basic to all sites, the only variable being the number of modules developed at each site. Other elements of the land treatment concept vary with the size and topography of the particular site. These elements are discussed in the following sections.

Surface Water Intercepting Ditch

Most of the land treatment sites intersect existing surface drainage systems. To prevent uncontrolled surface waters from entering a treatment site, an upland intercepting ditch was deemed necessary. This ditch can be located inside the boundry of a treatment site or on easements similar to present county drain practices. These ditches would divert the upland surface runoff to existing drainage channels that by-pass the treatment sites or pass through the sites in special corridors. Many of the existing channels would require some corrective work to improve their discharge capacities.

Buffer Strip

A buffer strip or "transition zone" is required along the perimeter of the land treatment sites. This zone would be used for fences, access and patrol roads, signs, water transmission canals, groundwater control ditches, landscaping, aesthetic enhancement, and aerosol drift containment.

A 100-300 foot wide strip is required depending upon the type of irrigation system selected. The center pivot systems with impact sprinkler nozzles mounted on top of the lateral and the fixed set sprinkler systems would require the greater buffer width in order to prevent aerosol drift outside the treatment site. Graded border and/or furrow irrigation would require the least width, because they have no aerosol drift problems. The center pivot system with spray nozzles pointed downward would require an intermediate width buffer.

The amount of aerosol drift is dependent upon wind velocity, height of spray pattern, and water droplet size. The CRREL Report (82) refers to California study in which a 5-10 mph wind caused the mist zone of a sprinkler with a normal spray radius of 30 feet to extend downwind 105 feet. The spray radius of the fixed set irrigation system studied is approximately 85 feet. Another reference (57) indicates that the zone of measurable moisture shifted downwind approximately 10 feet due to a wind velocity of 14.5 mph. The normal spray radius in the above reference was 61 feet. The extent of the "mist zone" as

compared to the "measurable moisture" zone was not given, but probably was considerably greater. Field testing prior to detailed design should be undertaken to determine more precisely the relationship between aerosol drift and wind velocity.

Effluent Transmission to Irrigation Modules

The effluent from the treatment and storage lagoons is assumed available at the upland border of the irrigation sites. The effluent may arrive at this point either by gravity or pumping depending upon the location and design of the treatment storage lagoons.

Within the irrigation sites, the incoming effluent flows by gravity in open canals to the pump stations located in each irrigation module. Drop structures in the canals will be used to control water elevations.

The renovative concept is based on the irrigation water passing through at least five feet of aerobic soil and having a growing crop present to take up the nutrients removed from the water. Neither of these conditions would exist for water lost directly from the incoming canals to the groundwater system. The pervious nature of some of the soils in the sites will require some type of lining to prevent infiltration of the irrigation water into the groundwater. Clay, PVC sheets, and concrete were considered as alternates for lining the canals. Gravity flow concrete pipe was also considered for distributing the effluent throughout the sites.

Collection of Renovated Water

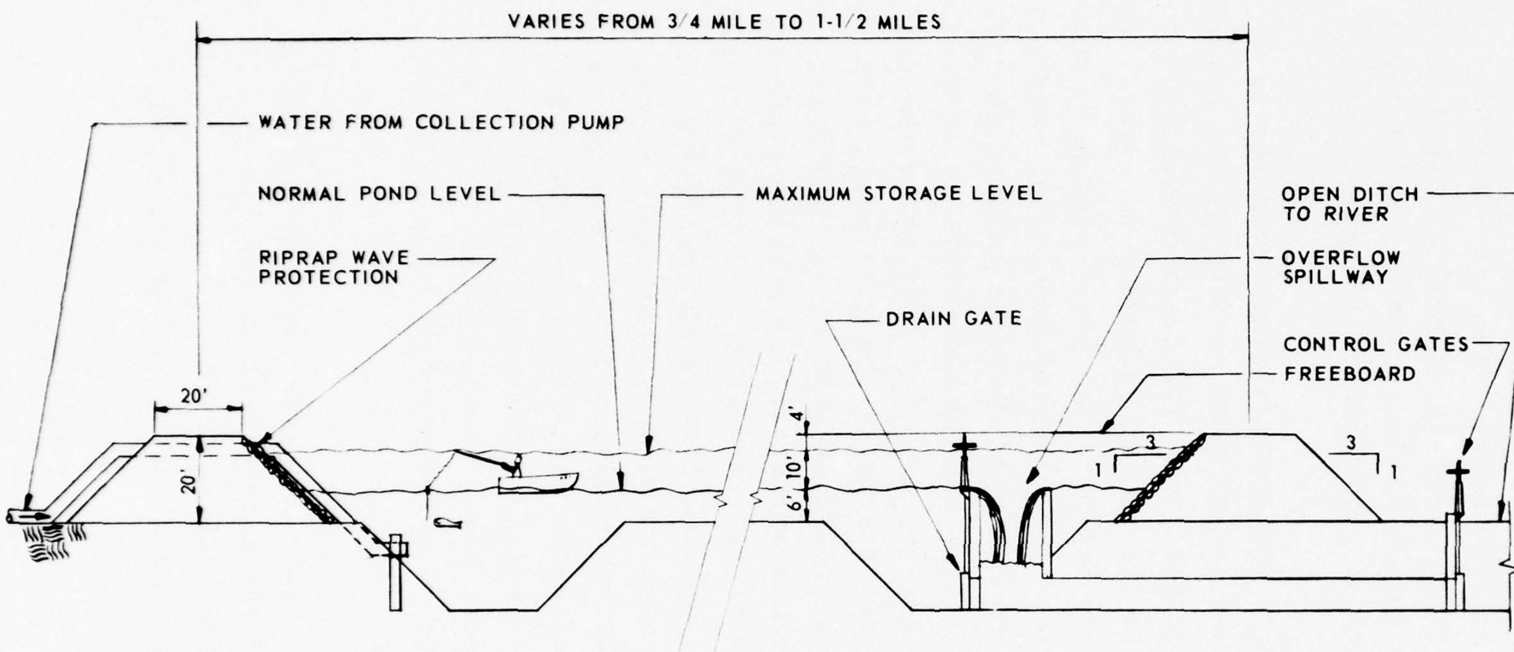
After the effluent from the treatment and storage lagoons has passed through the "living filter," the renovated water is collected in tile underdrain systems and flows by gravity through submains and mains to the lower edge of an underdrain module. At this point, the collected percolate is lifted by low head pumps and discharged into open canals for transmission to the reuse storage facility.

Since the collected percolate has been through the renovative cycle, it is not necessary to keep it separated from the groundwater for contamination reasons. Therefore, unlined canals can be used for the collected percolate transmission. Lining of these canals may be required for short sections of highly pervious soils in order to prevent hydraulic overload of adjacent underdrains.

Lined and unlined canals and concrete pipe were considered for the collected percolate transmission system.

Reuse Storage Facilities

Reuse storage ponds are located near the perimeter of the land treatment sites, at low drainage points, and near streams or large bodies of water such as Saginaw Bay, Lake Huron, or Lake Erie. The collected percolate will be pumped into the reuse storage ponds from the drainage canals. Under normal conditions the water will flow through the pond (Figure III-12) to the receiving body of water.



TYPICAL SECTION THRU REUSE PONDS

Figure III-12

The reuse storage ponds serve two functional roles in the land treatment process as well as representing potential reuse possibilities. The potential reuse possibilities are discussed later in this section.

Functionally, the reuse storage pond serves as a quarantine area and equalizing pond where the collected percolate will be monitored for desired quality before being released to the receiving bodies of water. The 10 feet of storage depth in the ponds will hold approximately 10 days flow of collected percolate. Under present policies, the State of Michigan permits controlled discharge into streams and public waters as long as the resulting water quality does not fall below the desired standards. Should this policy be continued, then the reuse storage pond could be used as an equalizing pond for unacceptable concentrations of certain elements that might unexpectedly pass through the "living filter." During these periods the flow to the receiving body of water would not stop completely, but would be cut back to the point that the addition of the elements to the receiving body of water would not cause the water quality to fall below desired quality standards. The available storage time under these conditions would vary depending on the percentage of percolate flow that is passed on to the receiving body.

Second, the reuse pond can serve as a holding reservoir should the water level in the rivers rise to the point that the addition of the percolate to the river might create flooding conditions. Again, partial flow

out of the pond would be permitted; therefore, the storage time would be greater than 10 days. Normally 10 day storage would be sufficient to permit the high stage of the rivers to pass.

Figures III-13, III-15, and III-17 indicate typical gage height - discharge relationships for rivers in the study area at particular gaging stations. The change in river state caused by adding various quantities of collected percolate can be determined from these curves. For example, using Figure III-13, assume a base river flow of 1000 cfs (gage = 4.0'); add 500 cfs collected percolate flow; total flow = 1500 cfs (gage = 4.6'); therefore, change in river stage due to adding 500 cfs equals 0.6 feet. These curves represent only one gaging station on each river and do not reflect the river response at all points downstream. The exact response of the river stage to discharged percolate quantities requires information and detail investigations beyond the scope of this project.

In the event contaminated water reaches the reuse storage facilities and cannot be discharged into the streams, a means of pumping this water to the treatment and storage lagoons was designed and costed.

Outfall Structures

The collected percolate will be routed to discharge points on nearby rivers or large bodies of water through open canals. An outfall structure is required to blend

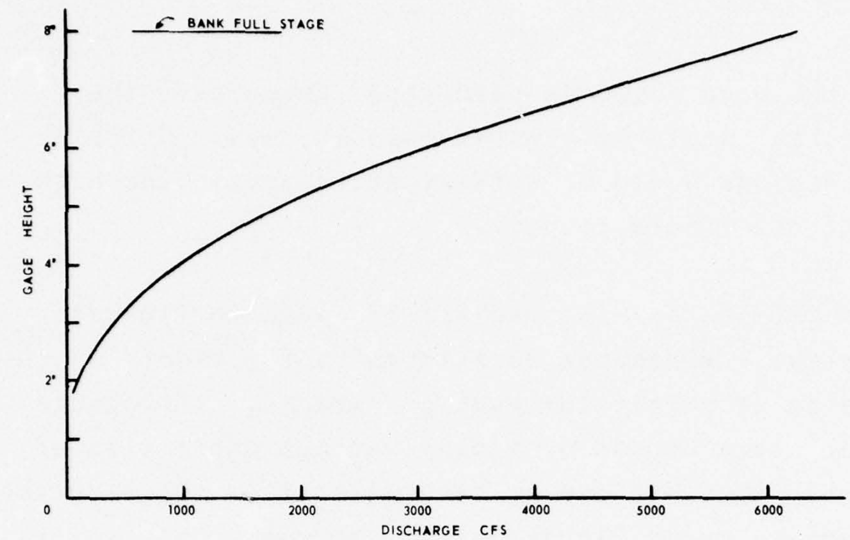


Figure III-13. **GAGE READING — DISCHARGE CURVE RIVER RAISIN NEAR MONROE, MICH.**

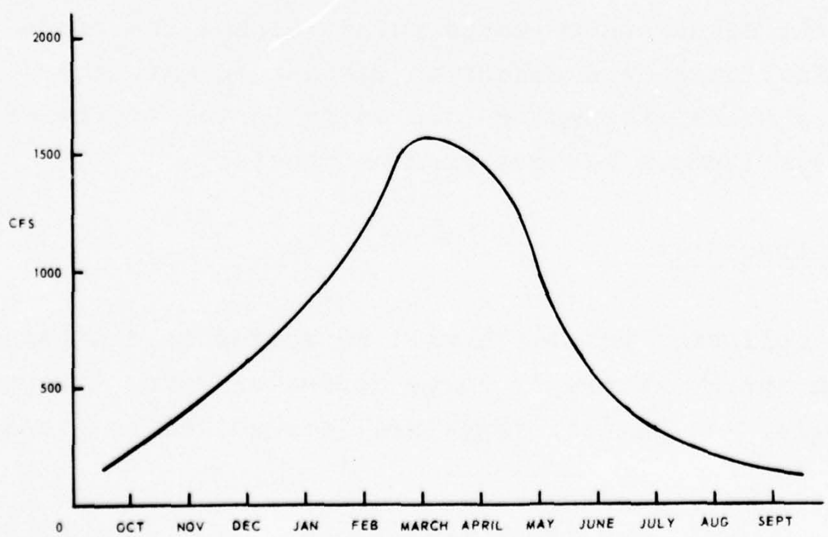


Figure III-14. **AVERAGE CFS/MO. FOR PERIOD 1937 THRU 1969 RIVER RAISIN NEAR MONROE, MICH.**

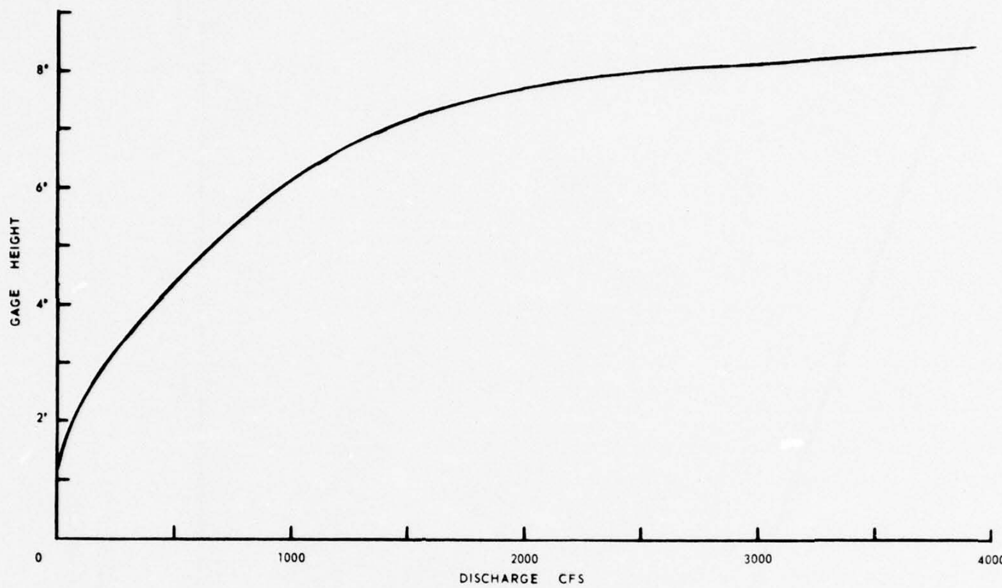


Figure III-15. **GAGE READING—DISCHARGE CURVE BELLE RIVER AT MEMPHIS, MICH.**

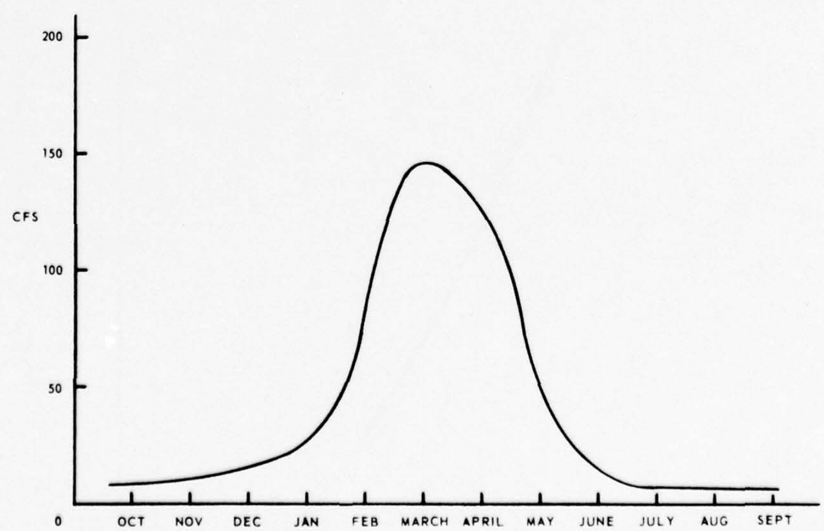


Figure III-16. **AVERAGE CFS/MO. FOR PERIOD 1963 THRU 1966 BELLE RIVER AT MEMPHIS, MICH.**

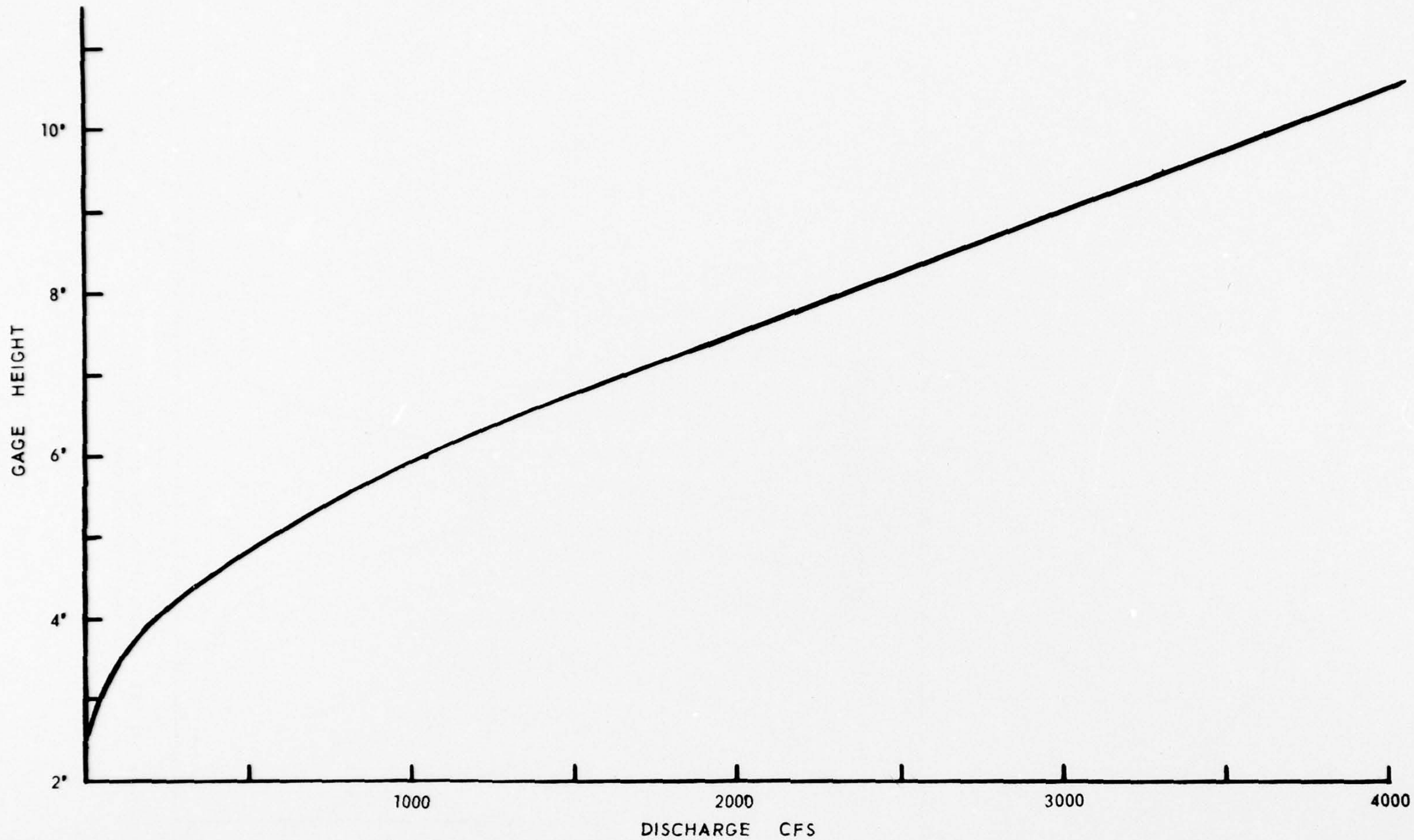


Figure III-17. **GAGE READING—DISCHARGE CURVE MILL CREEK NEAR ABBOTTSFORD, MICH.**

the discharge flow with existing river flow to minimize the hydraulic disturbance of the existing channel. Figure III-18 illustrates a drop-type spillway structure that will lower the incoming water to the river level and decrease the velocity of the incoming stream. Rip-rap bank protection is needed to prevent bank erosion.

Canals discharging into the large bays and lakes may require rock jetties or outfall pipes to prevent near-shore currents from building sandbars or causing shore erosion. Natural streams presently discharge into these large bodies of water essentially under equilibrium conditions. Detail studies of each discharge point will be required to determine the exact needs for protective structures.

Disinfection

The effluent from the treatment and storage lagoons requires disinfection prior to being irrigated onto the land. Common methods for large scale disinfection include chlorination, ozonation, and sodium hypochloride (Table III-2). Lesser used methods include ultraviolet light, chlorine dioxide, potassium permanganate, silver compounds, and iodine. A developmental product, bromine chloride is being studied. Chlorination is the most widely used method in the country today.

Chlorination is somewhat less effective than certain methods, but is more economical. Therefore, chlorination is the recommended method. Another contractor will develop designs and costs for disinfection.

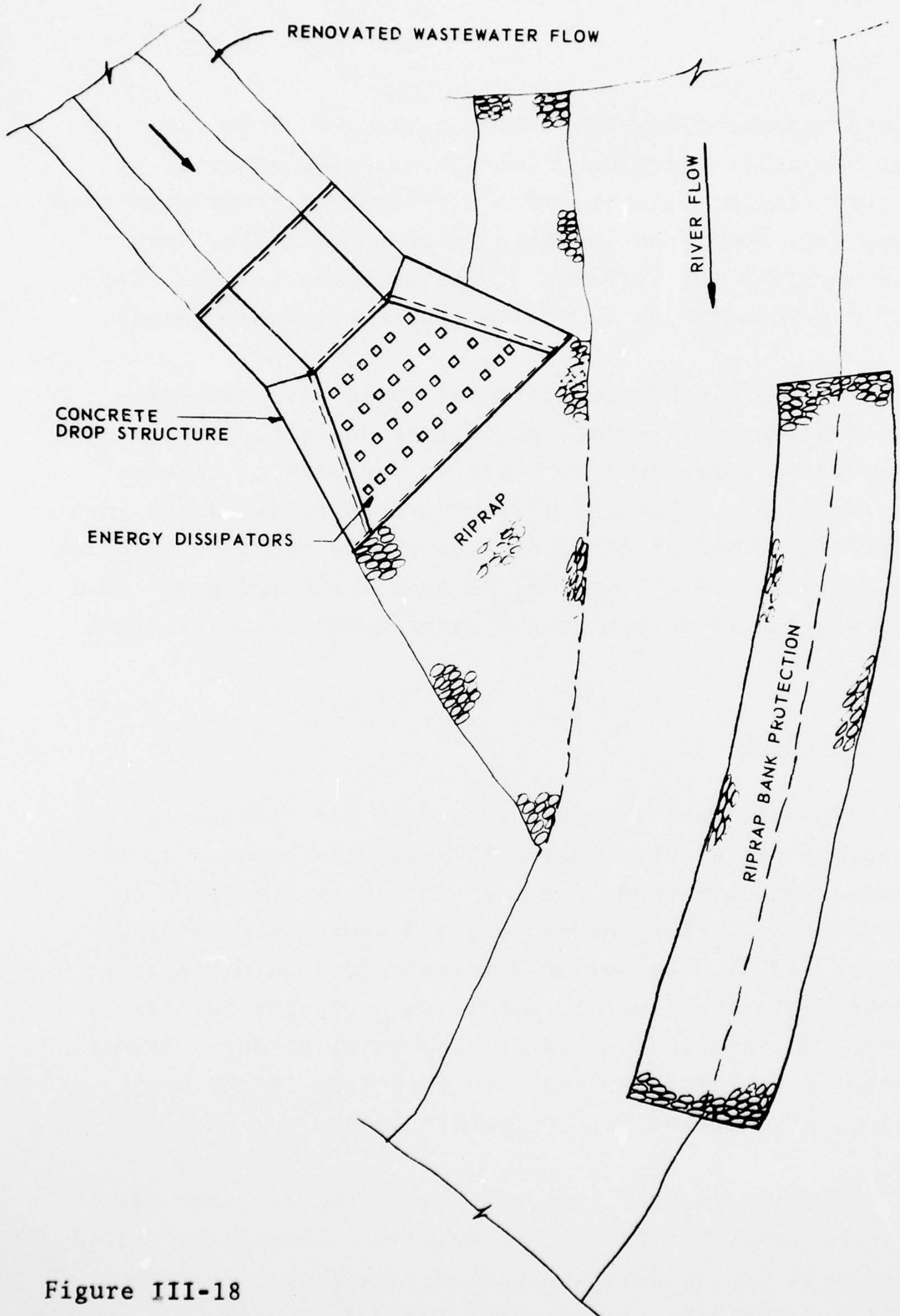


Figure III-18

Typical Outfall
Discharging Renovated Water

RIVER OUTFALL

Table III-2

Summary of Alternate Disinfection Methods

Method	Advantages	Disadvantages	Average Total* Cost/10^6 Gal
Chlorination	Common practice Reliable Good equipment Fairly effective	Hazardous chemical Toxic end products Corrosive Tastes and odors	$4.90
Sodium Hypo-chlorite (*in situ*)	Cost Non-hazardous	Volume of chemical Corrosive Toxic end products Taste and odor	$4.00-$5.56
Bromine Chloride	Very effective Non-toxic end products Cost Reaction time	Developmental Hazardous chemical Highly corrosive	$2.90
Ozonation	Kills viruses Very effective Non-toxic end products Reduces tastes and odors Removes color Reaction time	Cost Explosive No measurable residual Requires low solids water	$13.00

*Includes debt retirement, operation and maintenance costs
Plant size 64 MGD

Table III-2 (Continued)

Method	Advantages	Disadvantages	Average Total Cost/10^6 Gal
Sodium Hypochlorite	Non-hazardous	Cost Corrosive Toxic end products Tastes and odors Volume of chemical	\$9.00
Ultraviolet Light	Non-hazardous	Requires low solids water Time Low color water Specialized equipment Small scale application	>\$13.00
Chlorine Dioxide	Reaction time Destruction of tastes and odors	Hazardous Toxic end products Very corrosive Small scale application	>\$13.00

Sludge Disposal

Presently, sewage sludges and solid wastes in Southeastern Michigan are incinerated at separate facilities. Incinerator expansion and location to accommodate the sludge from the Southeastern Wastewater Management Program is not foreseen.

Under the land treatment alternative for wastewater management, lagoons are used for sewage treatment and for storage of the resulting effluent. After digestion of raw and biological solids, sludge will accumulate in the lagoons at about 0.9 tons of dry solids per million gallons of wastewater. The sludge must be periodically removed.

This sludge at about 3-5% concentration can be dredged from the lagoons and irrigated onto agricultural land within Southeastern Michigan. Sludge application should be made on land in close proximity to the lagoons, but not on the same land used for the wastewater irrigation site. Potential sludge disposal sites near the Monroe and St. Clair sites are shown in Section VI. All percolate from the sludge treatment site should be collected in an underdrain system. Soils similar to those used for wastewater irrigation should be acceptable for sludge treatment. Various other studies sponsored by the CORPS will further characterize land treatment of sludges.

The above described sludge handling procedure is not compatible with existing solid waste handling procedures in Southeastern Michigan.

REUSE CONSIDERATIONS

The renovated wastewater, having passed through the "living filter," has several potential uses. These uses include many of those normally drawing from a water resource whether involved with the water per se, a body of water or a watercourse. The quality of the renovated wastewater is assumed to be about equal to domestic water supply standards. But, those uses which would involve direct or indirect human consumption likely will be avoided until more is learned about the renovated wastewater.

Water Users

Water uses therefore could include irrigation, industrial processing (non-food), industrial cooling and stream augmentation. Except for the later, a pumping system and distribution network would be required causing delivery costs to the user. Costs would be slightly less than piping in municipal water because of no treatment and storage costs. However, today's construction costs vs. older systems may cause the "savings" to be small, dependent on locations of supply pond and user.

An example of industrial cooling use where the supply ponds could be advantageous is the proposed Detroit Edison Greenwood Energy Center (north central St. Clair County). Presently, the alternative cooling water sources for this energy center require new pipe construction. This new pipe construction would be about 9.5 miles to Lake Huron, 12 miles to the Port Huron municipal system, or many miles to the City of Detroit treated water system. A fourth short pipeline possibility might be to tap into the City of Detroit raw water supply line which runs along the south border of the energy center site. Another possibility is the Greenwood Energy Center could use renovated wastewater from the St. Clair irrigation site. Two of the reuse ponds designed at this site are only 1.5 and 4 miles from the energy center. At capacity the Greenwood Energy Center requires 400 MGD of make-up water for spray cooling in 4000 acre (6.25 square miles) spray cooling ponds. This would amount to 40% of the average output of the St. Clair site when irrigating or 59% average yearly output if accumulated and released uniformly. Some of the other common interest in ponds should also prove beneficial if the government agency versus private interface is not too difficult.

Provisions are to be made for routing a significant fraction of the renovated water into nearby streams which can help assure controlled augmentation during low flow periods. The fisherman, boater and admirer of pretty streams are the beneficiaries of this use of the renovated water. The aquatic life forms are kept in

their naturally healthy conditions. The stream bed remains fresh and free flowing at all times rather than stagnating or drying up.

Water Body Users

A distinction has been made between users of gallons of water and the users of a body of water or watercourse. The latter includes recreational pursuits, possibly water transportation, and aesthetic appearance of bodies of water. These are often interrelated and tend to come back to the use offering the most benefits - the recreational aspects.

The naturalness of the renovated water ponds or small lakes would be most inviting to the outdoor recreationalists, particularly if plans included stocking with game fish, camping conveniences, etc. As a minimum, most of the ponds would have features allowing shoreline or small boat fishing such as the present "Public Access" areas supported by the Michigan Department of Natural Resources. Some of the ponds would be suitable for more extensive park facilities which would encourage more small boat activities including sailing and water skiing. Later as the system matures, game and picnic areas, bathing beaches, and camping facilities would be added in those special cases where the pond characteristics and cost/benefit ratios are favorable.

All of the recreational site development should move forward at a regulated pace for several reasons:

a. The ponds need time to balance out the aquatic life cycle and grow natural plants in the water and along shore.

b. Game fish stocks cannot be introduced before pond balance, and then after stocking they require several years to develop.

c. Reuse ponds near Lake Huron may have little alternative attraction unless the fishing or fish is better; cost/benefit ratios may not merit funding until more fishing areas are needed to meet demand.

d. The public would need time and some good experiences regarding the ponds to reaffirm that the water is clear, sweet and good tasting (possibly contrary to their earlier suspicions).

Points made in c. and d. hint that public response may be disappointingly slow at first. Naturalists will recognize and promote the ponds' values for wildlife and aquatic propagation. But pressures from overcrowded existing recreational sites will be the greatest force to start using the ponds.

Perhaps the augmented streams will receive much more response from users. Certainly the source of the water will be much less a psychological factor. Some streams may be revitalized with more water flow than just augmentation amounts. This flow, plus increased depth from weirs in specific reaches and some interesting stocked fish, would make ideal fishing streams. Others

may be attracted also - canoe enthusiasts, hikers and picnickers. Additionally, some of the river and stream corridors could be developed as park areas.

SECTION IV

ECONOMICS AND UNIT COSTS

Irrigation site locations and alternative designs were presented in the preceding sections. This section develops costs for land, equipment, and construction. The following general bases were followed:

1. Costs are estimated in January 1972 dollars with no adjustment for future inflation.

2. The economic life of the facility is 50 years. Maintenance and replacement will continue throughout the 50 years to preserve utility. Salvage value after 50 years is considered nil.

3. No interest is charged during construction.

4. Base interest rate is 5-1/2 percent for sinking funds and capital recovery. Summary data are calculated at 7 percent and 10 percent to show interest effects.

5. The sinking fund factor is calculated according to paragraph 15, "ECONOMIC EFFECT," Computation of Financial Costs and Economic Costs, EM-1120-2-104, Manual - Corps of Engineers, 7 Nov. 1958. For example: Life, 50 years; Interest, 5.5 percent; Replacement, 16 years.

Solution: Present Worth of $1 16 yrs from now	=	$0.4246
" " " " 32 yrs " "	=	.1803
" " " " 48 yrs " "	=	.0772
Sum	=	.6821
Cap. recovery factor, 50 yrs	=	.05906
Sinking Fund Factor = Cap. Rec. x Sum of P.W.	=	.04029

Appendix B contains factors for other years and interest rates.

6. ANNUALIZED COSTS equals the sum of the operating costs, maintenance, sinking fund for replacement equipment and capital recovery.

LAND ACQUISITION

Land and property acquisition costs were determined for land within gross acreage boundaries of the sites. Total acquisition costs include current market value for property, including homesteads and buildings, family relocation allowances, and administrative, legal and contingency costs. The gross area includes the river corridors.

The current market value was investigated in some depth in the Monroe and St. Clair Counties. In Monroe, section by section assessed valuation was made available and compared to the average for the township. Variation was noted but the average was a good approximation of the township. St. Clair County had gathered considerable data regarding the equalization updating effects which helped establish the difference between equalized

valuations made 1, 2, and 3 years earlier and the January 1972 market value. Coded data from actual sales were available for some townships. The resulting factor was market value = 1.12 x 2 x equalized valuation. Data from each of the remaining counties covering the townships' assessed and equalization valuations were used with the above factor to calculate the market values.

The Ohio counties have a different system. Discussions with a county auditor revealed the assessed value to be approximately 39 percent of market value. Data for Fulton County were used as a guide for the Williams County estimate.

Relocation of the families currently living within a potential site were assigned at $5000 per family. The number of families was determined by counting dwelling units on aerial photographs, from population data obtained from SEMCOG* or from county plat books.

Based on experience of Michigan Department of State Highways, the cost of acquisition of properties incurs expenses over and above the market value and relocation. Administration of the procurement effort, legal and court costs on a minor portion of the cases are the bulk of the additional expenses. Some contingencies were included to make a total of 10 percent of the market value and relocation costs. Table IV-1 summarizes the land acquisition costs without river corridors and Appendix C shows the costs of the sites if the river corridors were included.

*Southeastern Michigan Council of Governments

Table IV-1

LAND ACQUISITION COSTS BY SITE

(M $ = $1000)

	Huron-Tuscola	St. Clair	Monroe	Lenawee	Fulton-Williams
Size, Acres	388,970	149,220	41,040	18,300	113,985
Square Miles	608	233	64	29	178
Land Acquisition, M $	258,099	91,233	44,472	17,565	77,120
$/Acre	664	611	1,084	960	677
Family Relocation, M $	26,491	10,650	6,957	1,527	14,936
Families	5,298	2,130	1,391	305	2,987
Administration, Legal, etc., M $	28,431	10,190	5,144	1,909	9,206
Total, M $	313,021	112,073	56,573	21,001	101,262
$/Acre	805	751	1,378	1,148	888

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MODULAR UNIT COST

Cost estimates are based upon price levels of January 1, 1972. Adjustments of costs to conform with this date were made using Engineering News Record (ENR) Construction Cost Indices.

Unit costs used to establish capital costs were taken from manufacturer's prices, contactor bid prices, estimating guides such as Dodge - Estimating Guide For Public Works Construction (18), Building Construction Cost Data, 1972 (8), Commercial-Industrial Construction Estimating & Engineering Standards, 1972 (16), unit price bid comparisons from ENR, and unpublished unit cost experience of The Dow Chemical Company.

The capital costs of the various irrigation and drainage modules were established by costing out the components of each module. These modular cost tables are presented in this section and are based on the description of the modules as given in Section III.

Certain components such as land leveling and erosion control are dependent upon the topography and unit cost for different values of land slope were developed. Costs corresponding to average slopes for the irrigation sites are used in developing the overall site cost summaries.

Annual operating and maintenance (O&M) costs are presented as the sum of maintenance, supplies, energy, labor, and replacement cost. Maintenance costs are presented as percentages of capital cost. Energy costs are based on horsepower requirements and anticipated hours of use. Labor costs are based on organizational

tables and annual salaries as presented later in this Section. Annual replacement costs are based on total replacement cost times sinking fund factors corresponding to the various replacement schedules. The replacement schedules used for this study are presented in Table IV-2. The annual interest rate used in the replacement cost calculations was 5 1/2 percent.

Table IV-2

Replacement Schedules for Irrigation and Drainage Module Components

Component	Years
Irrigation rigs	25
Concrete drainage structures	25
Control gate structures	25
Major electric motors	25
Large pump columns	16
Centrifugal pumps	16
Valves and risers	10
Sprinkler heads	8
Furrows	5

Table IV-3

Capital Cost for Design Module of Center Pivot Irrigation Rigs Giving 76% Land Coverage

Components	Units	Unit Cost	Cost
Irrigation Pumping Station	1-1200 HP	142,000	$142,000
Irrigation Rigs			
1300 ft Radius	16 ea.	18,000	288,000
Pressure Pipe			
16" CA	22,400 LF	17.28	387,000
18" CA	11,200 LF	23.87	267,000
24" Steel	5,200 LF	33.02	171,700
30" Steel	3,000 LF	42.70	128,100
Valves & Misc. Fittings	1 module	25,000	25,000
TOTAL			$1,408,800

Table IV-4

Operation and Maintenance Costs for
Design Module of Center Pivot Irrigation Rigs
Giving 76% Land Coverage

<u>Maintenance and Supplies</u>	
Irrigation Pumping Station @ 1.0% Capital	$ 1,400
Irrigation Rigs @ 2.0% Capital	5,800
Pressure Pipe @ 0.1% Capital	1,000
Valves & Miscellaneous @ 3.0% Capital	800
<u>Energy</u> @ 0.0125/Kilowatt-hr	
Pumping Station - 1200 HP @ 2800 hrs	42,000
Irrigation Rigs - 120 HP @ 2800 hrs	4,200
<u>Labor</u>	
3.9 men at $16,500	64,400
<u>Major Replacements</u>	
Irrigation Pumping Station @ 0.0149 x Capital	2,100
Irrigation Rigs @ 0.01955 x Capital	5,600
Pressure Pipe @ 0.01955 x 1/2 Capital	9,500
TOTAL O&M	$136,800

Table IV-5

Capital Cost for Design Module of Center Pivot Irrigation Rigs Giving 91% Land Coverage

Components	Units	Unit Cost	Cost
Irrigation Pumping Station	1-1600 HP	169,000	$169,000
Irrigation Rigs			
1300 ft Radius	16 ea.	18,000	288,000
600 ft Radius	18 ea.	8,500	153,000
Pressure Pipe			
6" CA	12,000 LF	5.48	65,700
8" CA	19,200 LF	6.68	128,300
16" CA	14,000 LF	17.28	241,900
18" CA	11,200 LF	23.87	267,300
24" Steel	8,400 LF	33.02	277,400
30" Steel	5,200 LF	42.70	222,000
36" Steel	3,000 LF	55.35	166,000
Valves & Misc Fittings	1 module	25,000	25,000
TOTAL			$2,003,600

Table IV-6

Operation and Maintenance Costs for
Design Module of Center Pivot Irrigation Rigs
Giving 91% Land Coverage

Maintenance and Supplies	
Irrigation Pumping Station @ 1.0% Capital	$ 1,700
Irrigation Rigs @ 2.0% Capital	8,800
Pressure Pipes @ 0.1% Capital	1,400
Valves & Miscellaneous @ 3.0% Capital	800
Energy @ 0.0125/Kilowatt-hr	
Pumping Station - 1600 HP @ 2800 hrs	56,000
Irrigation Rigs - 200 HP @ 2800 hrs	7,000
Labor	
4.8 men at $16,500	79,200
Major Replacements	
Irrigation Pumping Station @ 0.0149 x Capital	2,500
Irrigation Rigs @ 0.01955 x Capital	8,600
Pressure Pipe @ 0.01955 x 1/2 Capital	13,700
TOTAL O&M	$179,700

Table IV-7

Capital Cost for Design Module of Center Pivot Irrigation Rigs Giving 95% Land Coverage

Components	Units	Unit Cost	Cost
Irrigation Pumping Station	1-1600 HP	169,000	$169,000
Irrigation Rigs			
1450 ft Radius	16 ea.	20,000	320,000
Pressure Pipe			
16" CA	21,000 LF	17.28	362,900
20" CA	10,400 LF	29.12	302,800
30" Steel	5,000 LF	33.02	165,100
36" Steel	4,000 LF	42.70	170,800
Valves & Misc. Fittings	1 module	25,000	25,000
TOTAL			$1,461,000

Table IV-8

Operation and Maintenance Costs for
Design Module of Center Pivot Irrigation Rigs
Giving 95% Land Coverage

Maintenance and Supplies	
Irrigation Pumping Station @ 1.0% Capital	$ 1,700
Irrigation Rigs @ 2.0% Capital	6,400
Pressure Pipe @ 0.1% Capital	1,000
Valves & Miscellaneous @ 3.0% Capital	800
Energy @ 0.0125/Kilowatt-hr	
Pumping Station - 1600 HP @ 2800 hrs	56,000
Irrigation Rigs - 150 HP @ 2800 hrs	5,200
Labor	
3.9 men at $16,500	64,400
Major Replacements	
Irrigation Pumping Station @ 0.0149 x Capital	2,500
Irrigation Rigs @ 0.01955 x Capital	6,300
Pressure Pipe @ 0.01955 x 1/2 Capital	10,000
TOTAL O&M	$154,300

Table IV-9

Capital Cost for Design Module of Fixed Set Spray Irrigation (Underground Pipes)

Components	Units	Unit Cost	Cost
Irrigation Pumping Station	1-2300 HP	210,000	$210,000
Spray Heads	10,400 ea.	9.20	95,700
Spray Head Riser-2" pipe	93,600 LF	0.82	76,800
Pressure Pipe			
6" CA	1,040,000 LF	5.48	5,699,200
24" Steel	21,120 LF	33.02	697,400
30" Steel	21,120 LF	42.70	901,800
36" Steel	21,120 LF	55.34	1,168,800
42" Steel	25,940 LF	70.82	1,837,000
Valves			
42" motor operated	16 ea.	7500.00	120,000
Controller & Misc.	1 module	5000.00	5,000
TOTAL			$10,811,700

Table IV-10

Operation and Maintenance Costs for
Design Module of Fixed Set Spray Irrigation
(Underground Pipes)

Maintenance and Supplies	
Irrigation Pumping Station @ 1.0% Capital	$ 2,100
Spray Heads, Risers, Valves & Controller @ 2.0% Capital	6,000
Pressure Pipe @ 0.1% Capital	10,300
Energy @ 0.0125/Kilowatt-hr	
Pumping Station - 2300 HP @ 3000 hrs	86,200
Labor	
2.8 men at $16,500	46,200
Major Replacements	
Irrigation Pumping Station @ 0.0149 x Capital	3,000
Spray Heads @ 0.10197 x Capital	9,800
Risers @ 0.07767 x Capital	6,000
Valves @ 0.07767 x Capital	9,300
Pressure Pipe @ 0.01955 x 1/2 Capital	103,000
TOTAL O&M	$281,900

Table IV-11

Capital Cost for Design Module of Graded Border Irrigation

Components	Units	Unit Cost	Cost
Concrete lined head ditch with flow control	160,000 L.F.	$ 12.00	$1,920,000
Gate Structure	32 each	2,500	80,000
Land Leveling (Change to 0.4% Slope)			
If - 0.1% Slope	2,500 acres	46.00	115,000
0.2% Slope	2,500 acres	38.00	95,000
0.4% Slope	2,500 acres	29.00	72,500
1.0% Slope	2,500 acres	76.00	190,000
2.0% Slope	2,500 acres	118.00	295,000
4.0% Slope	2,500 acres	230.00	575,000

Table IV-12

Operation and Maintenance Costs for Graded Border Irrigation

		Slope of Land	
Maintenance and Services		1.0%	0.1%
Concrete lined head ditches with flow controls	@ 1.0% Capital	$ 19,200	$ 19,200
Gate Structure	@ 1.0% Capital	800	800
Land Leveling	@ 1.0% Capital	19,000	11,500
Labor			
3.9 men at $16,500		64,300	64,300
Replacements			
Concrete lined head ditch with flow controls	@ 0.01955 x Capital	37,600	37,600
Gate Structure	@ 0.01955 x Capital	1,600	1,600
TOTAL O&M		$142,500	$135,000

Table IV-13

Capital Cost for Design Module of Furrow Irrigation

Components	Units	Unit Cost	Cost
Concrete lined head ditch with flow control	160,000 L.F.	$ 12.00	$1,920,000
Gate Structure	32 each	2,500	80,000
Land Leveling (Change to 0.4% Slope)			
If - 0.1% Slope	2,500 acres	46.00	115,000
0.2% Slope	2,500 acres	38.00	95,000
0.4% Slope	2,500 acres	29.00	72,500
1.0% Slope	2,500 acres	76.00	190,000
2.0% Slope	2,500 acres	118.00	295,000
4.0% Slope	2,500 acres	230.00	575,000
Furrows	2,500 acres	5.00	12,500

Table IV-14

Operation and Maintenance Costs for Furrow Irrigation

		Slope of Land 1.0%	Slope of Land 0.1%
Maintenance and Services			
Concrete lined head ditches with flow controls	@ 1.0% Capital	$ 19,200	$19,200
Gate Structure	@ 1.0% Capital	800	800
Land Leveling	@ 1.0% Capital	19,000	11,500
Furrow	@ 5.0% Capital	600	600
Labor			
3.9 men at $16,500		64,300	64,300
Replacements			
Concrete lined head ditch with flow controls	@ 0.01955 x Capital	37,500	37,500
Gate Structure	@ 0.01955 x Capital	1,600	1,600
Furrows	@ 0.179 x Capital	2,200	2,200
TOTAL O&M		$145,200	$137,700

Table IV-15

Capital Cost for Runoff Control Related to Irrigation Method Design Module

Irrigation Design Module	Units	Unit Cost	Cost
Center Pivot Irrigation Rigs	2560 acres	$15.00	$38,400
Center Pivot Irrigation Rigs on 0.1% sloping land with land cells on 100 ft center	2560 acres	$30.00	$76,800
Center Pivot Irrigation Rigs on 2.0% sloping land with land cells on 100 ft center	2560 acres	$60.00	$153,600
Fixed Set Irrigation	2560 acres	$15.00	$38,400
Graded Border Irrigation		not required	
Furrow Irrigation		not required	

Table IV-16

Operation and Maintenance Cost for Runoff Control
Related to Irrigation Method Design Module

Irrigation Design Module	Maintenance & Supplies @ 10.0% Capital	Labor 0.3 men @ 16,500	Total
Center Pivot Irrigation Rig	3,800	5,000	$8,800
Center Pivot Irrigation Rigs on 0.1% sloping land with land cells on 100 ft centers	7,700	5,000	$12,700
Center Pivot Irrigation Rigs on 2.0% sloping land with land cells on 100 ft centers	15,400	5,000	$20,400
Fixed Set Irrigation	3,800	5,000	$8,800
Graded Border	--	--	--
Furrow Irrigation	--	--	--

Table IV-17

Capital Cost for Design Module of Underdrain System with Laterals Spaced on 33.0 ft Centers

Components	Units	Unit Cost	Cost
Drainage Pumping Station	1-160 HP	43,000	$43,000
Drainage Pipe			
4" Plastic	3,163,000 LF	0.31	980,500
12" RCP	6,000 LF	5.54	33,200
15" RCP	4,560 LF	7.08	33,300
18" RCP	8,400 LF	9.51	79,900
21" RCP	12,000 LF	10.76	129,100
24" RCP	10,650 LF	13.32	141,900
30" RCP	2,640 LF	18.23	48,100
36" RCP	2,640 LF	24.74	65,300
48" RCP	2,640 LF	36.95	97,500
Clean-outs			
4 ft dia.	40 ea	521	20,800
5 ft dia.	3 ea	1000	3,000
TOTAL			$1,675,600

Table IV-18

Operation and Maintenance Costs for Design Module of Underdrain System with Laterals Spaced on 33.0 ft Centers

<u>Maintenance and Supplies</u>	
Drainage Pump Station @ 1.0% of Capital	$ 400
Drainage Pipe @ 2.0% of Capital	32,200
<u>Energy</u> @ 0.0125/Kilowatt-hr	
Pumping Station - 160 HP @ 5800 hrs	11,600
<u>Labor</u>	
0.3 men at $16,500	5,000
<u>Major Replacement</u>	
Drainage Pump @ 0.0149 x Capital	600
TOTAL O&M	$ 49,800

Table IV-19

Capital Cost for Design Module of Underdrain System with Laterals Spaced on 55.0 ft Centers

Components	Units	Unit Cost	Cost
Drainage Pumping Station	1-160 HP	43,000	$43,000
Drainage Pipe			
4" Plastic	1,324,000 LF	0.31	410,400
5" Plastic	590,000 LF	0.38	224,200
12" RCP	6,000 LF	5.54	33,200
15" RCP	4,560 LF	7.08	33,300
18" RCP	8,400 LF	9.51	79,900
21" RCP	12,000 LF	10.76	129,100
24" RCP	10,650 LF	13.32	141,900
30" RCP	2,640 LF	18.23	48,100
36" RCP	2,640 LF	24.74	65,300
48" RCP	2,640 LF	36.95	97,500
Cleanouts			
4 ft dia.	40 ea.	521.00	20,800
5 ft dia.	3 ea.	1,000.00	3,000
TOTAL			$1,329,700

Table IV-20

Operation and Maintenance Costs for
Design Module of Underdrain System with
Laterals Spaced on 55.0 Centers

Maintenance and Supplies	
Drainage Pumping Station @ 1.0% of Capital	$ 400
Drainage Pipe @ 2.0% of Capital	25,300
Energy @ 0.0125/Kilowatt-hr	
Pumping Station - 160 HP @ 5800 hrs	11,600
Labor	
0.3 men at $16,500	5,000
Major Replacement	
Drainage Pump @ 0.0149 x Capital	600
TOTAL O&M	$ 42,900

Table IV-21

Capital Cost for Design Module of Underdrain System with Lateral Spaced on 16.5 ft Centers and with Underground Asphalt Barrier

Components	Units	Unit Cost	Cost
Drainage Pumping Station	1-160 HP	43,000	$43,000
Drainage Pipe			
4" Plastic	6,324,000 LF	0.31	1,960,400
12" RCP	6,000 LF	5.54	33,200
15" RCP	4,560 LF	7.08	33,300
18" RCP	8,400 LF	9.51	79,900
21" RCP	12,000 LF	10.76	129,100
24" RCP	10,650 LF	13.32	141,900
30" RCP	2,640 LF	18.23	48,100
36" RCP	2,640 LF	24.74	65,300
48" RCP	2,640 LF	36.95	97,500
Cleanouts			
4 ft dia.	40 ea.	521.00	20,800
5 ft dia.	3 ea.	1,000.00	3,000
Asphalt Barrier	2500 acres	1,700.00	4,250,000
TOTAL			$6,905,500

Table IV-22

Operation and Maintenance Costs for Design Module of Underdrain System with Laterals Spaced on 16.5 ft Centers and with Underground Asphalt Barrier

Maintenance and Supplies	
Drainage Pump Station @ 1.0% Capital	$ 400
Drainage Pipe @ 2.0% Capital	51,800
Asphalt Barrier @ 2.0% Capital	85,000
Energy @ 0.0125/Kilowatt-hr	
Pumping Station - 160 HP @ 5800 hrs	11,600
Labor	
0.3 men at $16,500	5,000
Major Replacement	
Drainage Pump @ 0.0149 x Capital	600
TOTAL O&M	$154,400

UNIT COST FOR SITE RELATED FACILITIES

Site related components of the land treatment concept, such as effluent and percolate transmission canals, reuse storage facilities, outfall structures, pump stations, and administrative facilities, were designed and costed for specific size sites. From these specific designs, unit type estimated costs were developed, some related back to the number of modules per site, others to cost per mile of canal, or cost per mile of perimeter, or cost per acre of land purchased. These unit cost estimates have been used in developing the total costs for the sites described in Section VI.

Transmission Facilities

The costs for water transmission facilities were developed for gravity flow and pressure systems. The costs for pressure systems were developed in the irrigation module discussion presented previously. Gravity flow transmission systems were designed and costed as lined and unlined canals, and various types of pipe.

Canal designs were developed and costed for several different capacities. The costs were derived from pricing cubic yards of earthwork and square feet or square yards of lining. The required miles of the different size canals were determined from a system layout. An example of the calculations for a lined canal is given in Table IV-23 and for a pipe system in Table IV-24. Operating and maintenance costs are taken as a percentage of the capital cost.

Table IV-23

Example of Costing Irrigation Canals

Required Flow CFS	Length Miles	Earthwork Yd^3/Mile	Lining Ft^2/Mile	Earthwork Yd^3	Lining Ft^2
65	13	11,600	175,000	151,000	2,265,000
130	5.2	13,200	195,000	68,600	1,014,000
195	2.0	14,800	212,000	29,600	424,000
260	2.6	16,400	227,000	42,600	590,000
	22.8			291,800	4,293,000

Earthwork 292,000 Yd^3 @ $1.30/$Yd^3$ = $380,000

Lining 4,293,000 Ft^2 @ $0.15/$Ft^2$ = 644,000

TOTAL $1,024,000

Cost per mile: $1,024,000 ÷ 22.8 = $45,000/mile

O&M @ 1.0% = $450/mile

Note: As the size of the irrigation area serviced by a canal system increases, the average cost per mile will also increase. The cost per mile of canals with different types of linings was developed using this system, but varying the cost of the lining.

Table IV-24

Example of Costing Gravity Flow Pipe Systems

Required Flow CFS	Pipe Size Inches	Length Miles	Cost/Mile Installed $/Mile	Sub-Total $
65	48	13.0	185,000	2,405,000
130	66	5.2	264,000	1,373,000
195	78	2.0	370,000	740,000
260	84	2.6	423,000	1,100,000
TOTAL		22.8		5,618,000

Cost per mile: $5,618,000 ÷ 22.8 = $246,000

O&M @ 0.5% = $1230/mile

Pump Facilities

The required horsepower for pump stations was developed from the following formula:

$$HP = \frac{\text{Flow (gpm) x design head (ft)}}{\text{3960 x Efficiency}}$$

The capital cost of a pump station was determined by multiplying the horspower required by a cost per horsepower. Operating and maintenance costs include minor repair, energy usage, and replacement costs. Labor costs are covered in the overall operating cost. An example of this calculation is given in Table IV-25.

Table IV-25
Example of Costing Pumping Facilities

6000 HP @ $80/HP = $480,000

Maintenance and Supplies @ 1.0%	=	$ 4,800
Energy:		
6000 kwh x 5800 hr = 34,800,000 kwh		
34,800,000 x $0.0125/kwh	=	435,000
Replacement: $480,000 x 0.0149	=	7,000
TOTAL O&M		$446,800

Ratio of O&M to capital cost will vary depending on the running time of the pump.

Labor Cost

Labor costs for the different elements of the land treatment system are based on the organizational charts shown in Figures IV-1 and IV-2, and the

Figure IV-1

WASTE WATER MANAGEMENT ORGANIZATIONAL CHART

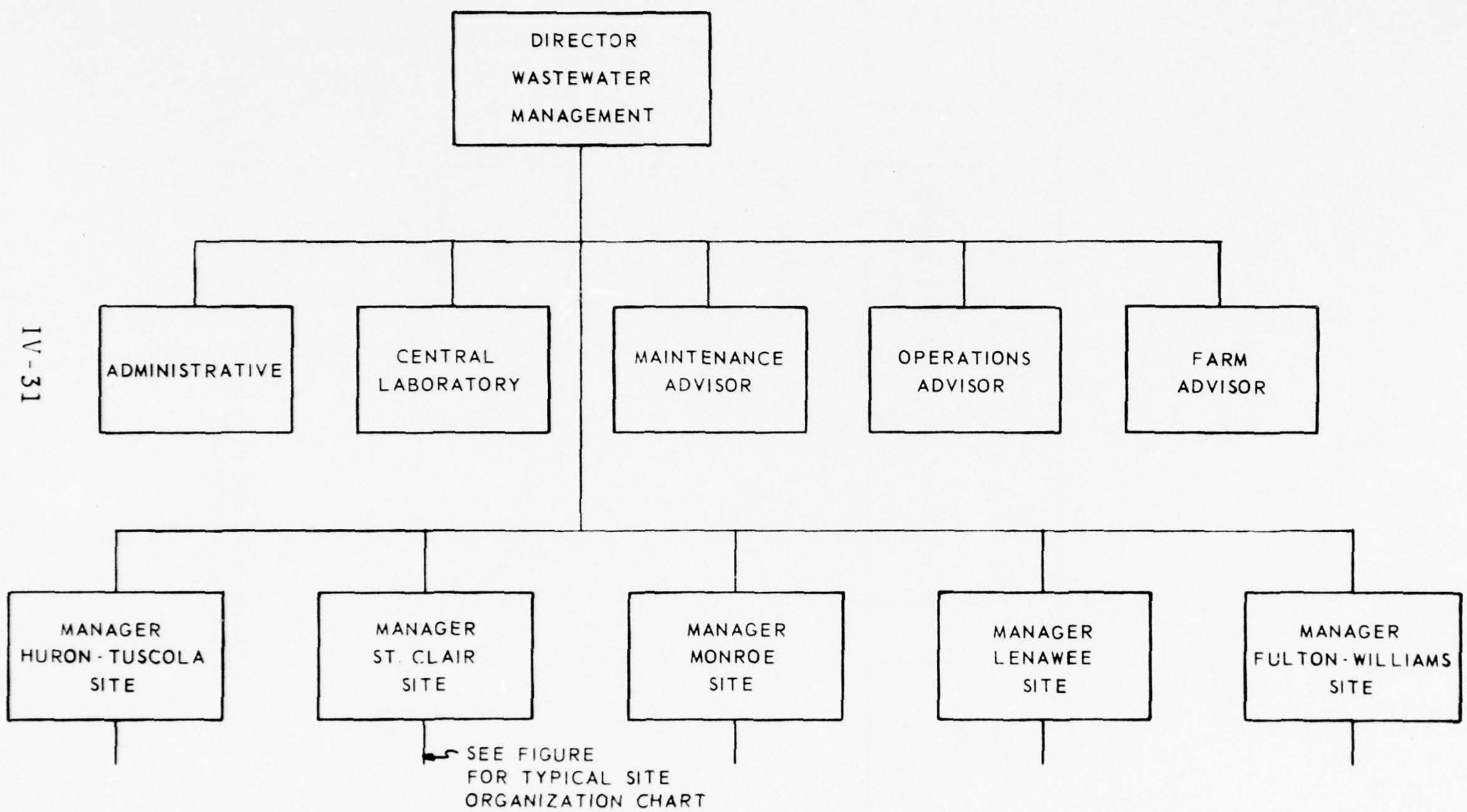
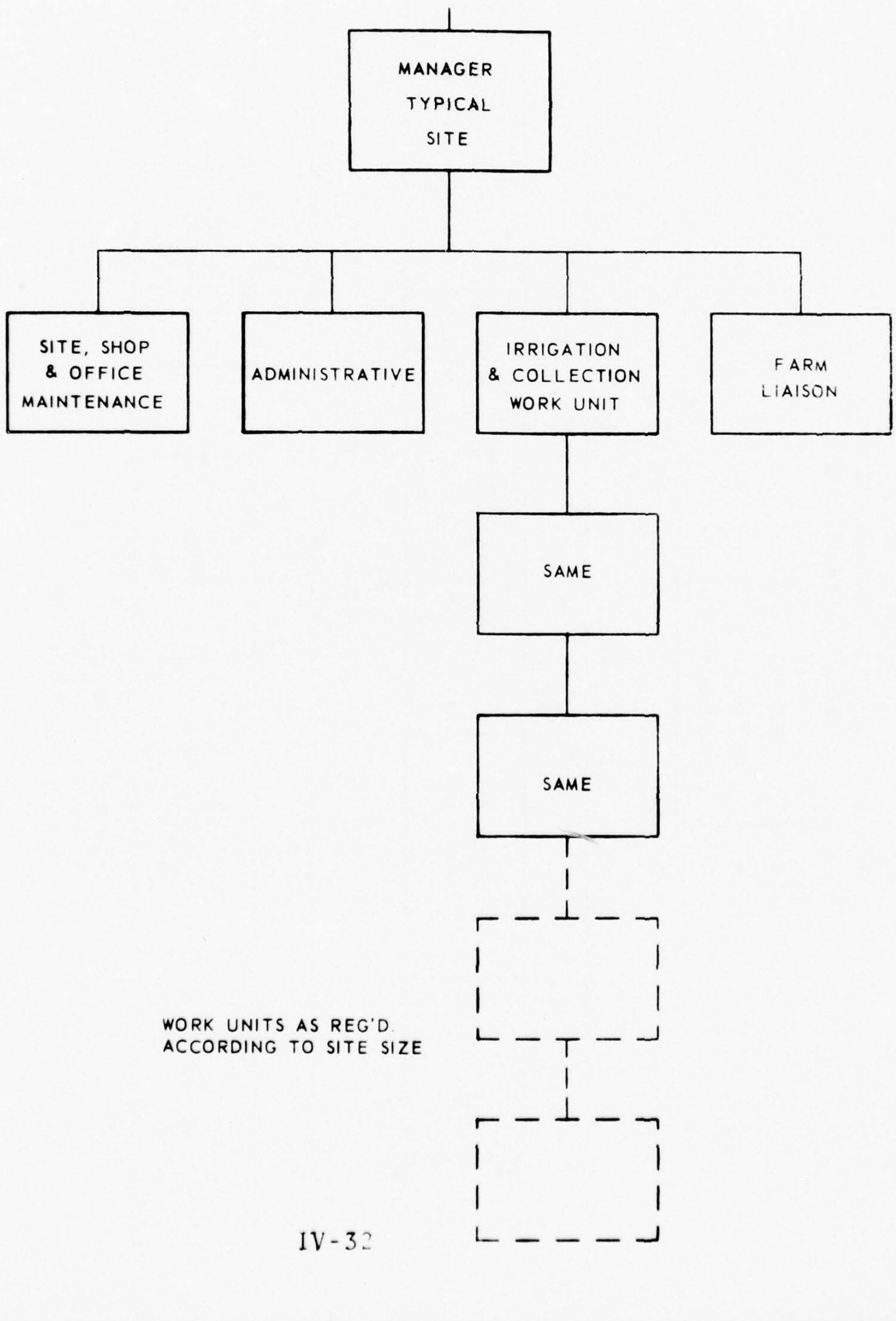


Figure IV-2 **WASTE WATER SITE ORGANIZATIONAL CHART**



schedules of personnel as shown in Tables IV-26, IV-27, and IV-28. Labor for the farm operations is not included in this report.* The labor costs shown in Table IV-28 are included in the operating and maintenance cost of the irrigation and drainage modules. The other labor costs are presented under site and project headings of the summary tables.

Central Laboratory

Considerable sampling and testing must be conducted to determine performance of the "living filter" and to develop irrigation, drainage, and farm management practices. This sampling and testing will be conducted by a central laboratory responsible for all five irrigation sites. Cost estimates were based upon taking "grab samples" using the schedule shown in Table IV-29. Some samples might only be analyzed for selected constituents deemed to be critical indicators. These selected constituents might be BOD, N, P, and one heavy metal. Other samples will be analyzed for all constituents including the heavy metals, microorganisms, etc. To balance people, instrumentation, and skill requirements during the year, certain sampling testing will be contracted to an outside commercial laboratory, specially equipped for heavy metal scans, plant and soil samples.

Costs for the Central Laboratory are shown in Tables IV-26 and IV-30.

*Costs of producing crops are assumed equivalent to revenue received for farm product. See Section VII.

Table IV-26

Project Administration and Laboratory
Labor Costs

Project Administrative Labor:					
1	Director	@	$30,000	=	$ 30,000
1	Farm Advisor	@	20,000	=	20,000
1	Maintenance Advisor	@	15,000	=	15,000
1	Operations Advisor	@	20,000	=	20,000
2	Administrators	@	14,000	=	28,000
8	Secretaries, Clerks	@	10,000	=	80,000
					$193,000
Central Laboratory Labor:					
1	MS Chemist	@	15,000	=	15,000
2	BS Chemist	@	12,000	=	24,000
12	Lab Technicians	@	10,000	=	120,000
4	Water Samplers	@	8,000	=	32,000
2	Drivers	@	6,000	=	12,000
1	Sample Clerk	@	10,000	=	10,000
					$213,000
Sub-Total Labor					$406,000
+ 25% Overhead					101,000
Total Labor					$507,000

Table IV-27

Site Administrative Labor for St. Clair Site
(An Example)

Manager	1	@	$24,000	=	$ 24,000
Farm Liaison	1	@	18,000	=	18,000
Administrator	1	@	14,000	=	14,000
Secretaries	2	@	8,000	=	16,000
Site, Shop and Office Maintenance	7	@	10,000	=	70,000
			+ 25% overhead		35,000
					$177,000

*Site administrative labor varies depending upon size of site.

Table IV-28

Irrigation and Drainage Work Unit

Labor Cost

(10 Modules - 40 miles^2)

1	Superintendent	@	$18,000	=	$ 18,000
4	Foremen	@	16,000	=	64,000
13	Operators	@	14,000	=	182,000
4	Electricians	@	12,000	=	48,000
4	Mechanics	@	12,000	=	48,000
16	Technicians	@	12,000	=	192,000
					$552,000
		+ 25% Overhead			138,000
	TOTAL				$690,000

Average annual cost/man

$690,000 ÷ 42 = $16,500

Labor cost per irrigation module

39 men ÷ 10 modules x $16,500 = $64,400

Labor cost per drainage module

3 men ÷ 10 modules x 16,500 = $ 5,000

These labor costs are included in the operating and maintenance costs for the irrigation and drainage modules.

Table IV-29

Sampling and Testing Schedule for Central Laboratory

Sample Sources	Daily-Selected	Weekly-Selected	Monthly-Selected	Quarterly-All	Annually-Selected	Annually-All
	Sampling Frequency and Constituents Analyzed					
Observation wells			X	X		
Farm wells (adjacent to irrigation site)			X			X
Reuse pond influent	X			X		
Reuse pond effluent		X		X	X	
Streams						
Above discharge point		X		X		
Below discharge point		X		X		
Plants and soils					X	

Administrative Facilities

Administrative offices and facilities were developed for the project level, the site level, and the work unit level. The capital cost and operating and maintenance cost for these facilities are shown in Tables IV-30 and IV-31.

Table IV-30

Capital Cost
Project Administrative and Central Lab

Administrative Offices	$300,000
Central Laboratory	120,000
Laboratory Equipment	190,000
TOTAL	$610,000

Operation and Maintenance Costs
Project Administrative and Central Laboratory

Maintenance, Supplies, and Utilities	$ 50,000
Vehicles 10 @ $1500	15,000
Contract Sample Testing	24,000
Replace lab equipment, 10-year Schedule $190,000 x 0.07767	14,800
Labor	507,000
TOTAL	$610,000

Table IV-31

Capital and O&M Costs for Site Administrative Facilities (St. Clair Site Used as an Example)

Capital Cost

Site Administrative Facilities (5000 SF) One per site	$102,000
Field Service Buildings (3000 SF) One for each 10 module work unit	54,000

Operating and Maintenance Cost

Site Administrative Facilities	
Supplies, Utilities, Maintenance	20,000
Vehicles 50 @ $1500	75,000
Labor	177,000
TOTAL	$272,000

These costs all vary with the size of the site.

Field Service Building	
Supplies, Utilities, Maintenance	3,000
Vehicles are covered under site cost and labor is covered in the module costs	

O&M per module $3000 ÷ 10 = $300

SECTION V
SELECTED DESIGN ALTERNATIVES

SITES

The Monroe, St. Clair, Huron-Tuscola, Lenawee, and Fulton-Williams sites are suitable for wastewater application. Soils are generally medium textured, highly capable of adsorbing wastewater constituents and have sufficient permeabilities to permit wastewater application. Land acquisition costs including family relocation and associated legal, administrative costs, etc. ranged from \$750 to \$1375 per acre for the five sites. If all five sites are not needed to treat all or some portion of the Southeastern Michigan wastewater, sites closer to wastewater sources should be perhaps utilized first to avoid excessive transmission costs. Perhaps the Huron-Tuscola site is preferred over the Fulton-Williams site (Ohio) to avoid problems from transmitting sewage water from one state to another. Because of uncertainties relating to wastewater flows, use of other wastewater treatment alternatives, etc., irrigation and collection facilities will be designed and costed for all five sites.

BUFFER STRIPS

A buffer strip 100-300 feet in width should exist along the perimeter of the wastewater irrigation site. The

spray irrigation method probably requires a buffer strip on the order of 300 feet; whereas, the graded border method of irrigation conceivably requires a narrower buffer strip. The buffer strip can be used for fences, roads, signs, canals, landscaping, etc. The buffer strip is needed to provide isolation, protection against wind drift, and aesthetic value to the irrigation site. Buffer strip should exist adjacent to public roads within the irrigation site. In the designs for five irrigation sites, a buffer strip of 300 feet width was used in all cases.

Major rivers run through the irrigation sites. In several cases, lands adjacent to these rivers present topographical problems. Additionally, these rivers are viewed as public property and as such should be accorded buffer protection from the wastewater irrigation sites. Hence, a corridor approximately one mile wide was reserved along these rivers to eliminate costs of correcting major topographical problems and to offer buffer protection for the rivers. Lands within these corridors are not considered part of the irrigation sites and are not included in land acquisition costs. Presumably, the corridors could be state owned and reserved for wildlife and recreational purposes. Corridors are included for the Fulton-Williams, St. Clair, Monroe, and Lenawee sites.

WASTEWATER APPLICATION

Some land treatment facilities in the United States operate year around and/or applied more than two inches

of wastewater per week. But, the average application of two inches per week for 35 weeks is judged the most suitable for the Southeastern Michigan Wastewater Management Program. This judgement is primarily based upon (i) climatic and growing season conditions, (ii) soil permeabilities, (iii) goals for wastewater renovation and (iv) performance of operating land treatment facilities. Detailed rationale for selecting the 70 inches of annual wastewater application was given previously in Section III.

DISINFECTION

Chlorination is the selected method for disinfecting the wastewater prior to land treatment. This selection is based primarily upon cost considerations. However, ozonation should be considered a close alternate. Ozonation is more effective on viruses, but is more costly compared to chlorination. Another contractor will design and cost the chlorination facilities.

TRANSMISSION TO IRRIGATION MODULE

Within the wastewater irrigation site, a clay lined channel is selected for water transmission to the irrigation module. This selection is based upon cost considerations. Lining of the channel insures that untreated wastewater is irrigated onto land rather than seeping from the canal into groundwater. Considerable water could seep from an unlined canal due to the pervious nature of some of the soils. Soil permeabilities

range from 0.2 to >10.0 inches per hour. Water seeping from an unlined canal fails to be completely exposed to the "living filter" and could be only partially renovated.

IRRIGATION METHOD

A center pivot irrigation system with land cells is the selected method for the four irrigation sites in Michigan. This selection is based primarily upon cost and reliability considerations. The design giving 95% coverage is preferred over the other considered center pivot irrigation systems. The 95% coverage design has the greatest overlap of irrigation circles, but allows the greatest land usage with a reasonable cost for irrigation equipment.

The graded border irrigation method is selected for design at the Fulton-Williams site (Ohio). This method costs slightly more than the 95% coverage center pivot irrigation systems. A requirement for graded border irrigation is relatively low soil permeabilities, which are provided by the Michigan and Ohio soils. Hence, this method utilizes the low soil permeabilities to an advantage; whereas, the low permeabilities must be considered a disadvantage for the spray irrigation methods. Compared to spray irrigation, graded border is expected to be less reliable for producing uniform water application.

Fixed set irrigation system is likely the most reliable system for producing uniform water application

and high performance for wastewater renovation. But, the fixed set system is 3-4 times more expensive than other methods.

UNDERDRAIN SYSTEM

A drainage system using a perforated tile lateral spacing of 33 feet is selected for underdrains. This spacing is based upon 0.2 inches per hour permeability, the lowest permeability found in the wastewater irrigation site soils. The underdrains are required to maintain at least a five foot depth of aerobic soil and to collect the renovated wastewater for reuse.

Many of the farms presently existing within the irrigation sites have tile drainage systems. These tile systems are necessary to drain the soils especially in the spring. Normally these farm tiles are placed 30-48 inches below the soil surface. Hence, existing tile drain systems are believed unsuitable for wastewater renovation because of insufficient aerobic soil depth.

An asphalt barrier to insure that applied wastewater is intercepted by the tiles was not recommended. Applied wastewater must pass through several feet of medium to fine textured soils even if the water table is below the tile drains. Such soils are believed highly effective for wastewater renovation and should eliminate the need for an asphalt barrier. With 70 inches of annual wastewater application, the water table will likely be maintained at the tile drainage depth. In this case,

the tile drains will intercept applied wastewater and negate the need for the asphalt barrier. The groundwater will be monitored. If unrenovated wastewater is detected in the groundwater, the irrigation of wastewater would be temporarily suspended and corrective measures taken. These measures probably will be similar to those taken if contaminated water is detected coming from the underdrains installed just above an asphalt barrier.

REUSE FACILITIES

An unlined channel is selected for transmission of the renovated water from the drainage modules to the storage facilities. The storage facility should be a holding pond sized to retain at least 6-10 days of underdrain water. Stream outfalls are required for discharging the renovated water.

GROUNDWATER AND WATER RUNOFF CONTROL

Observation wells are recommended for monitoring the groundwater. For planning purposes, a cluster of three wells is spaced about every three miles along the perimeter of the site. A ditch around the site to intercept groundwater is not recommended. Very little lateral movement of the applied wastewater is expected, especially under a buffer strip of about 300 feet width. However, a ditch to intercept upland runoff before it reaches the irrigation site is recommended. Water runoff and soil erosion control must be practiced on the irrigation site.

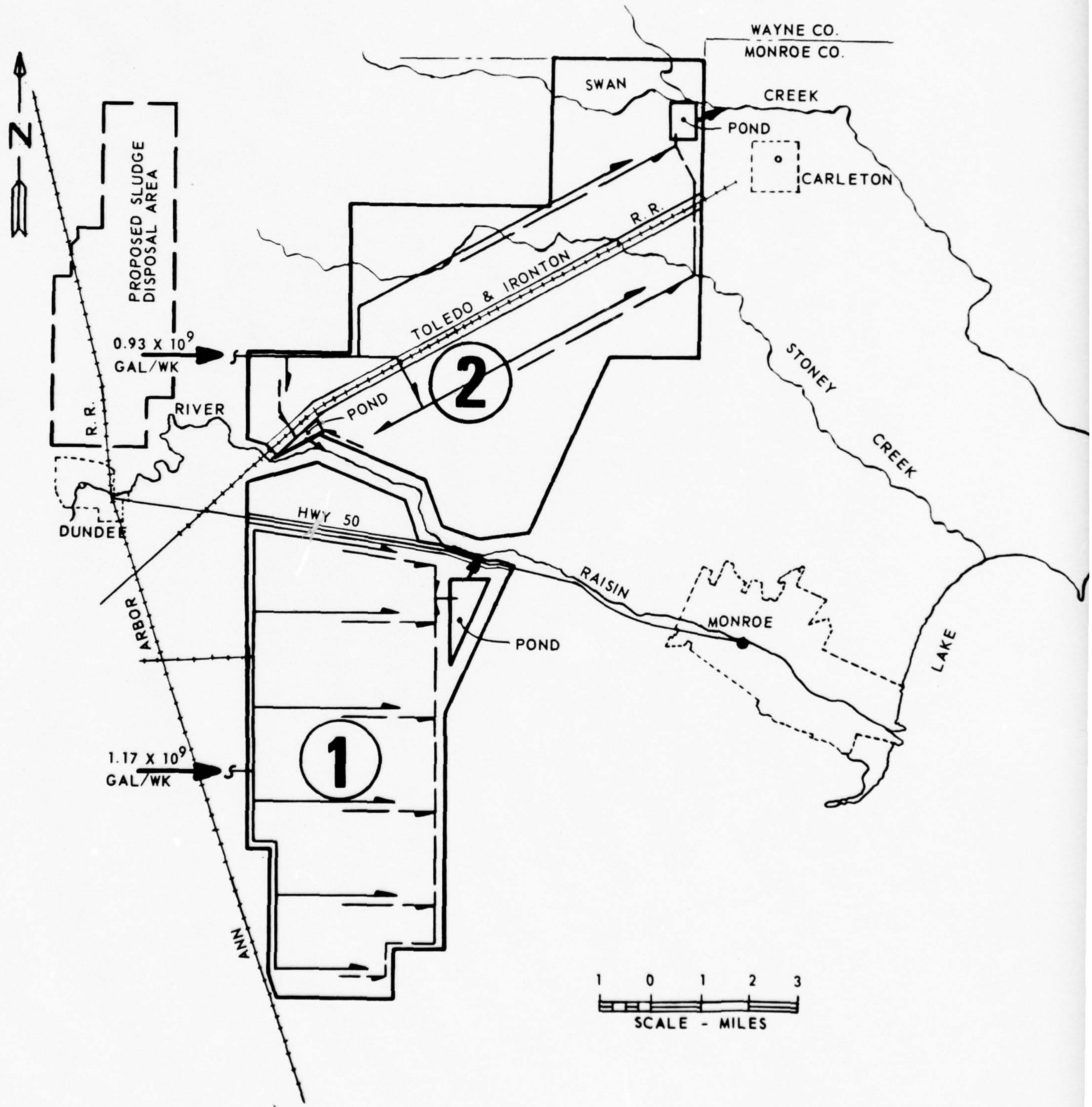
SECTION VI
DESIGNS AND COSTS FOR IRRIGATION SITES

DESIGNS

The Monroe site (Figure VI-1) consists of two subareas of approximately equal size. One subarea is located south of the River Raisin and the other to the north. The irrigation water inlets are located on the west side of the sites. The south subarea has a discharge point into the River Raisin and the north subarea has two discharge points, one into the River Raisin and the other into Swan Creek. The combined areas can treat 2.1 billion gallons of water a week or the equivalent of 201 million gallons per day (MGD) on an annual basis (Table VI-1).

The Lenawee site (Figure VI-2) is located on the River Raisin between Adrian and Blissfield. This site is divided into two subareas, the southwest site is approximately one-half the size of the northeast site. The irrigation water inlets for both sites are located on the west side. The southwest site has one discharge point and the northeast site has two discharge points. The combined treatment capacity of this site is 0.9 billion gallons per week or the equivalent of 86 MGD on an annual basis (Table VI-1).

The St. Clair site (Figure VI-3) consists of three subareas located partially in Macomb County, St. Clair County and Sanilac County. The south subarea is located



WAYNE CO.
MONROE CO.
SWAN
CREEK
POND
CARLETON
N
PROPOSED SLUDGE DISPOSAL AREA
R.R.
TOLEDO & IRONTON
0.93 X 10^9 GAL/WK
2
POND
RIVER
R.R.
STONEY
CREEK
DUNDEE
HWY 50
RAISIN
MONROE
POND
ARBOR
LAKE
1.17 X 10^9 GAL/WK
1
ANN
1 0 1 2 3
SCALE - MILES

1

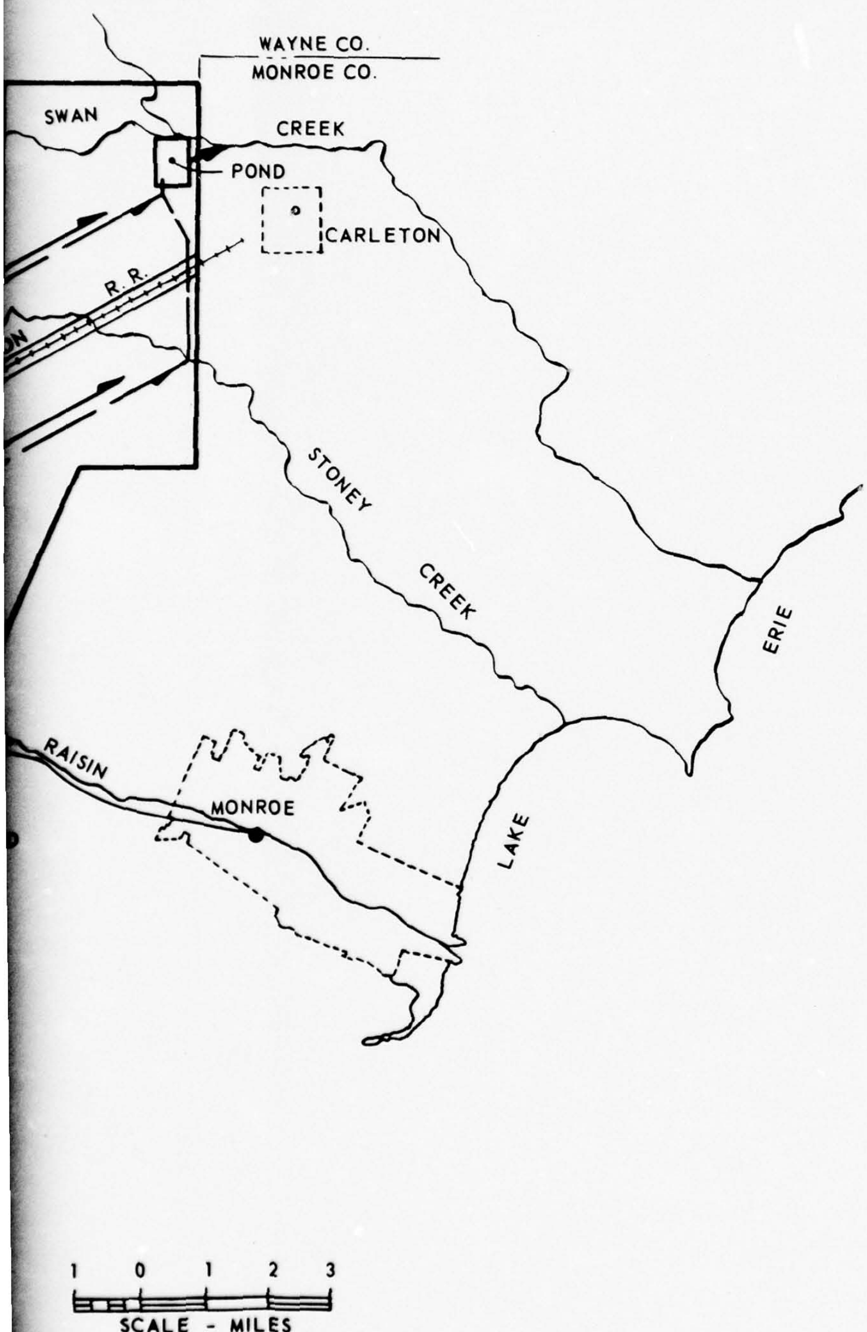


FIGURE VI-1

WASTEWATER TREATMENT DESIGN
MONROE SITE

2

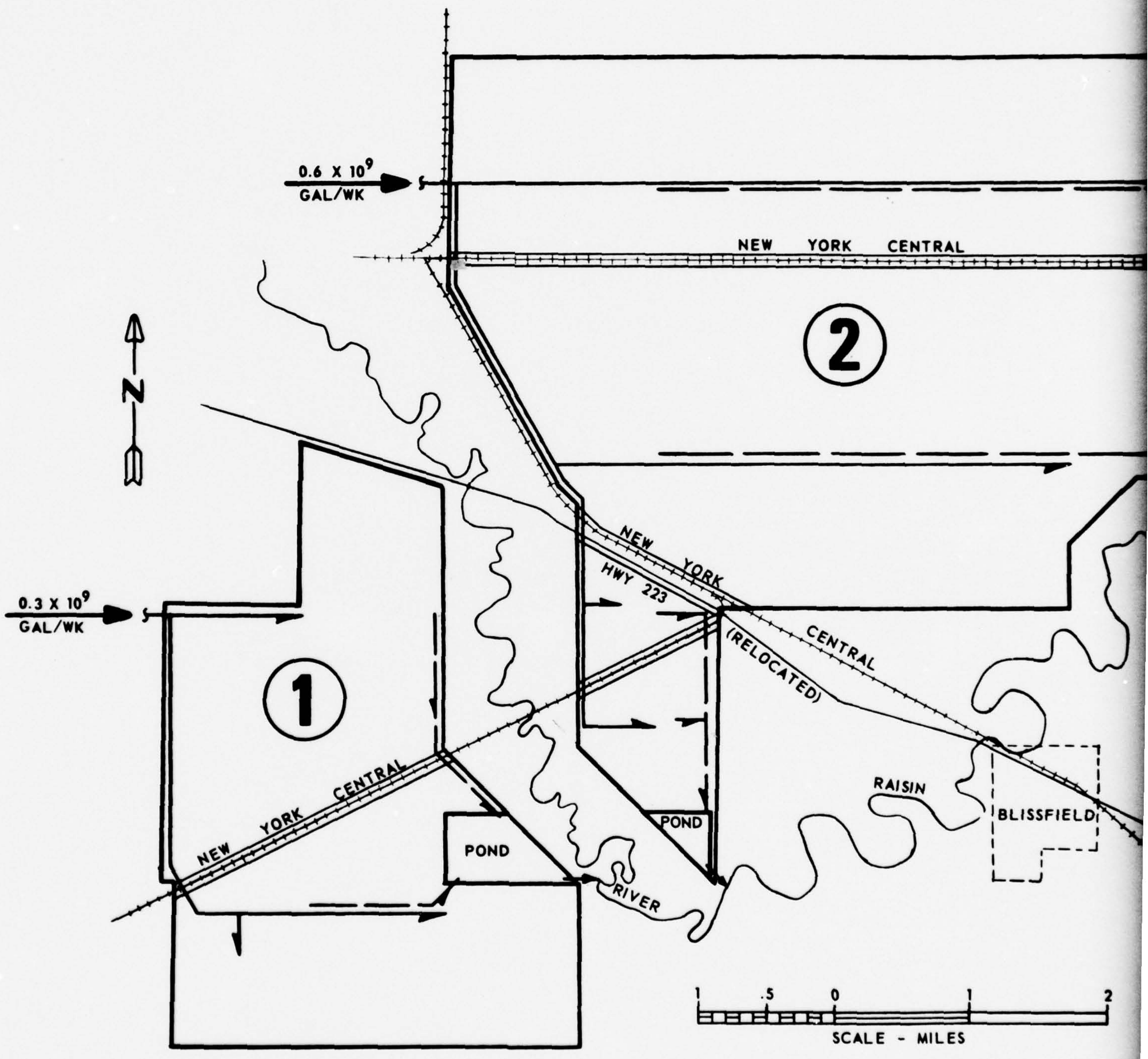
Table VI-1

Wastewater Application

Site	Gallons per Week	Annual Gallons*	Equivalent Daily Rate** (MGD)
Monroe	2.1×10^9	73.5×10^9	201
Lenawee	0.9×10^9	31.5×10^9	86
St. Clair	7.1×10^9	248.5×10^9	681
Huron-Tuscola	19.1×10^9	668.5×10^9	1,832
Fulton-Williams	5.9×10^9	206.5×10^9	566
TOTALS	35.1×10^9	1228.5×10^9	3,366

*Annual Gallons = gallons per week x 35 weeks

**Equivalent Daily Rate (MGD) = $\dfrac{\text{Weekly rate} \times 35 \text{ weeks}}{365 \text{ days} \times 10^6}$



0.6 X 10^9 GAL/WK
0.3 X 10^9 GAL/WK
N
NEW YORK CENTRAL
2
1
NEW YORK CENTRAL
HWY 223
(RELOCATED)
CENTRAL
NEW YORK CENTRAL
POND
POND
RIVER
RAISIN
BLISSFIELD
1 .5 0 1 2
SCALE - MILES

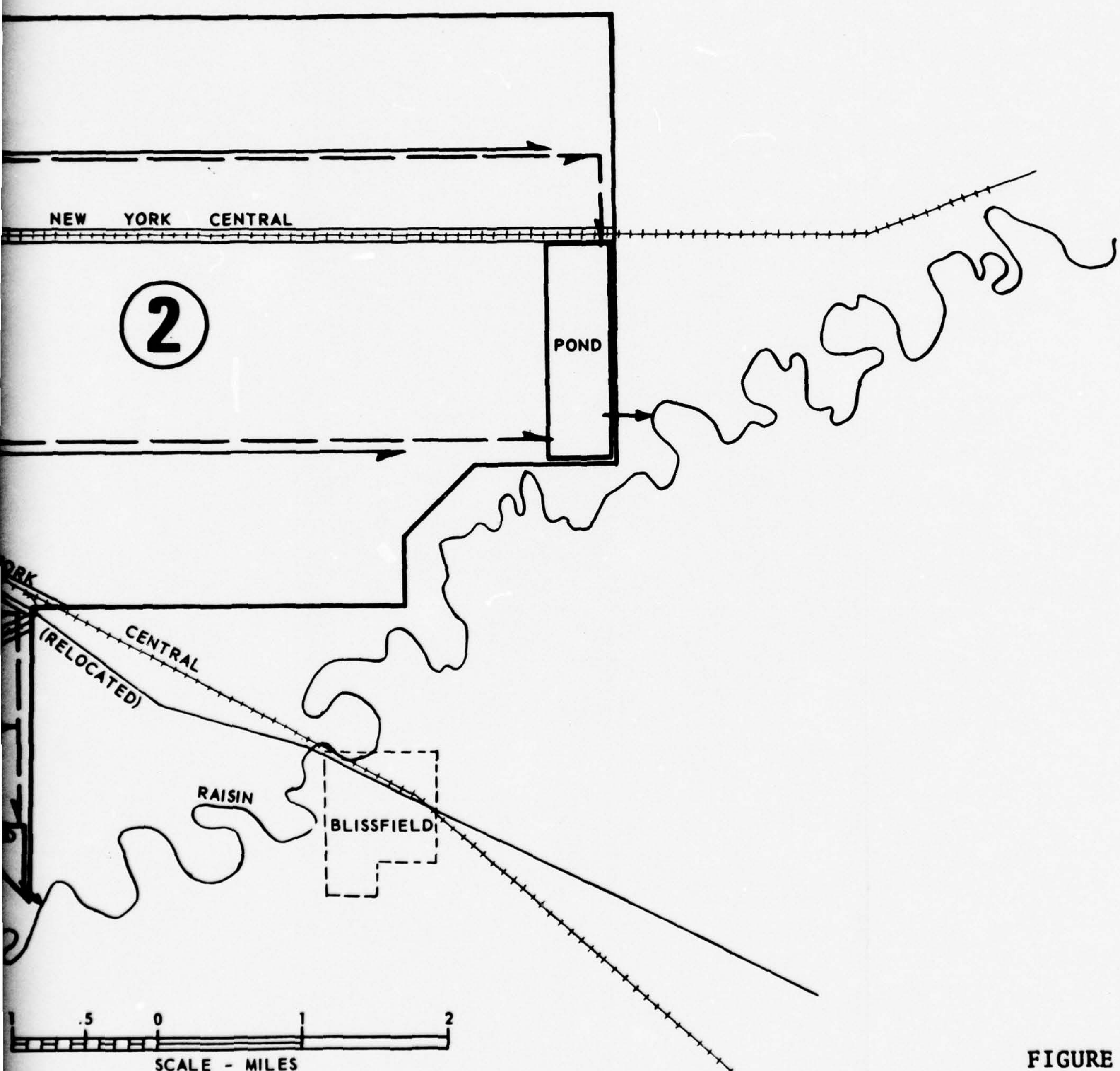
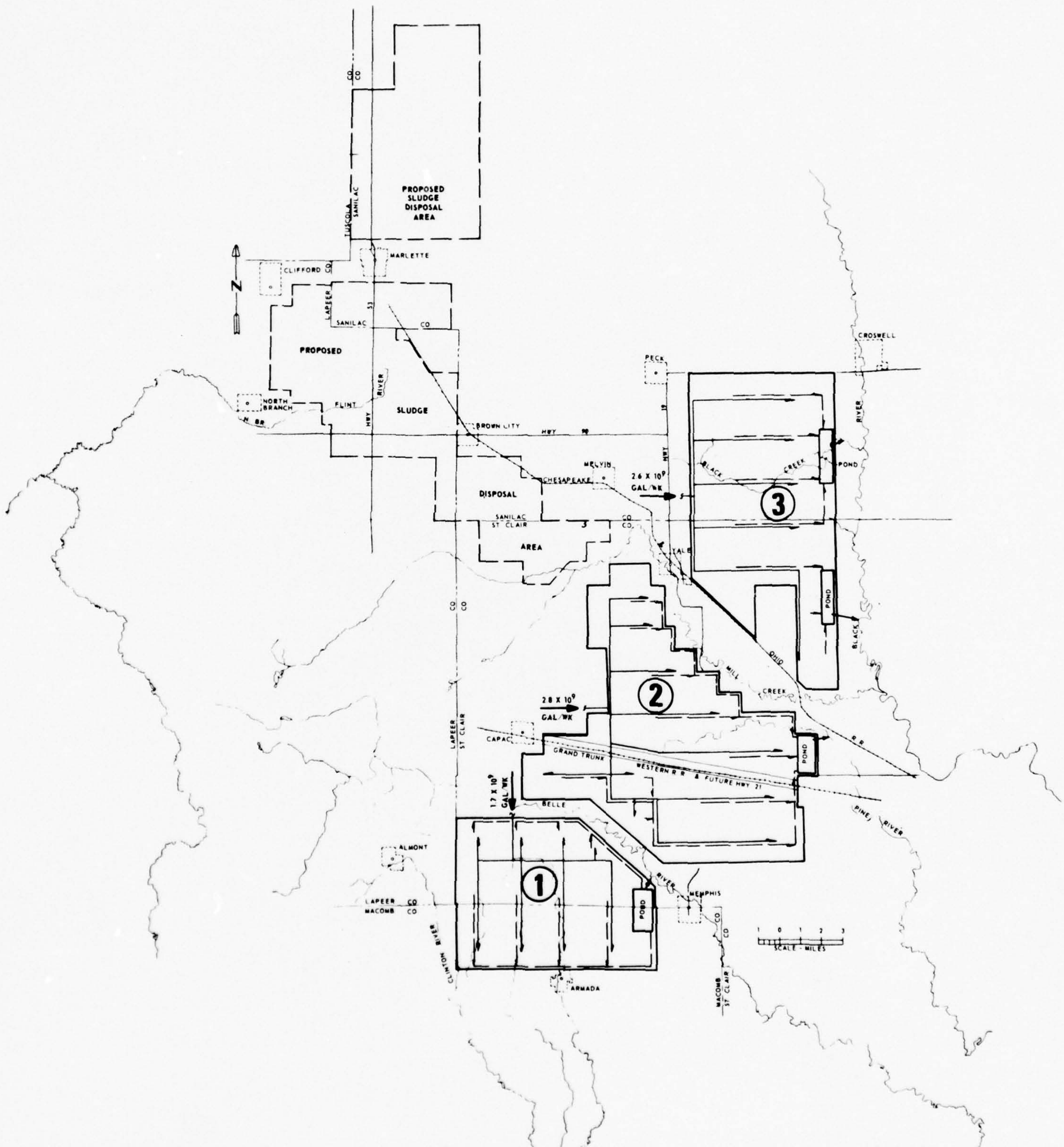


FIGURE VI-2
WASTEWATER TREATMENT DESIGN
LENAWEE SITE

2


PROPOSED
SLUDGE
DISPOSAL
AREA
TUSCOLA
SANILAC
CO
MARLETTE
CLIFFORD
LAPEER
SANILAC
CO
N
PROPOSED
SLUDGE
DISPOSAL
AREA
NORTH BRANCH
N BR
FLINT
RIVER
HWY 53
BROWN CITY
HWY 90
MELVIN
CHESAPEAKE
SANILAC
ST CLAIR
CO
PECK
CROSWELL
HWY 19
2.6 X 10⁹
GAL/WK
BLACK
CREEK
POND
3
RIVER
YALE
OHIO
BLACK
MILL
CREEK
2
2.8 X 10⁹
GAL/WK
CAPAC
LAPEER
ST CLAIR
CO
GRAND TRUNK
WESTERN R R & FUTURE HWY 21
R R
PINE RIVER
1.7 X 10⁹
GAL/WK
BELLE
RIVER
1
POND
ALMONT
MEMPHIS
LAPEER CO
MACOMB CO
CLINTON RIVER
ARMADA
MACOMB
ST CLAIR
SCALE - MILES

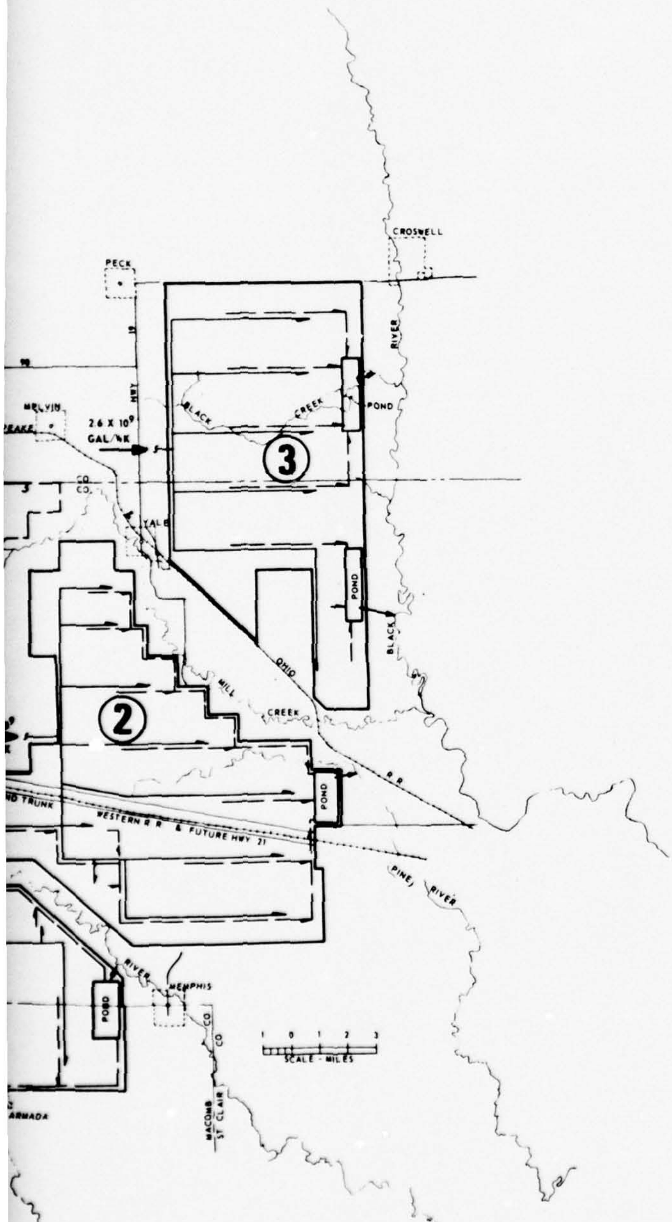
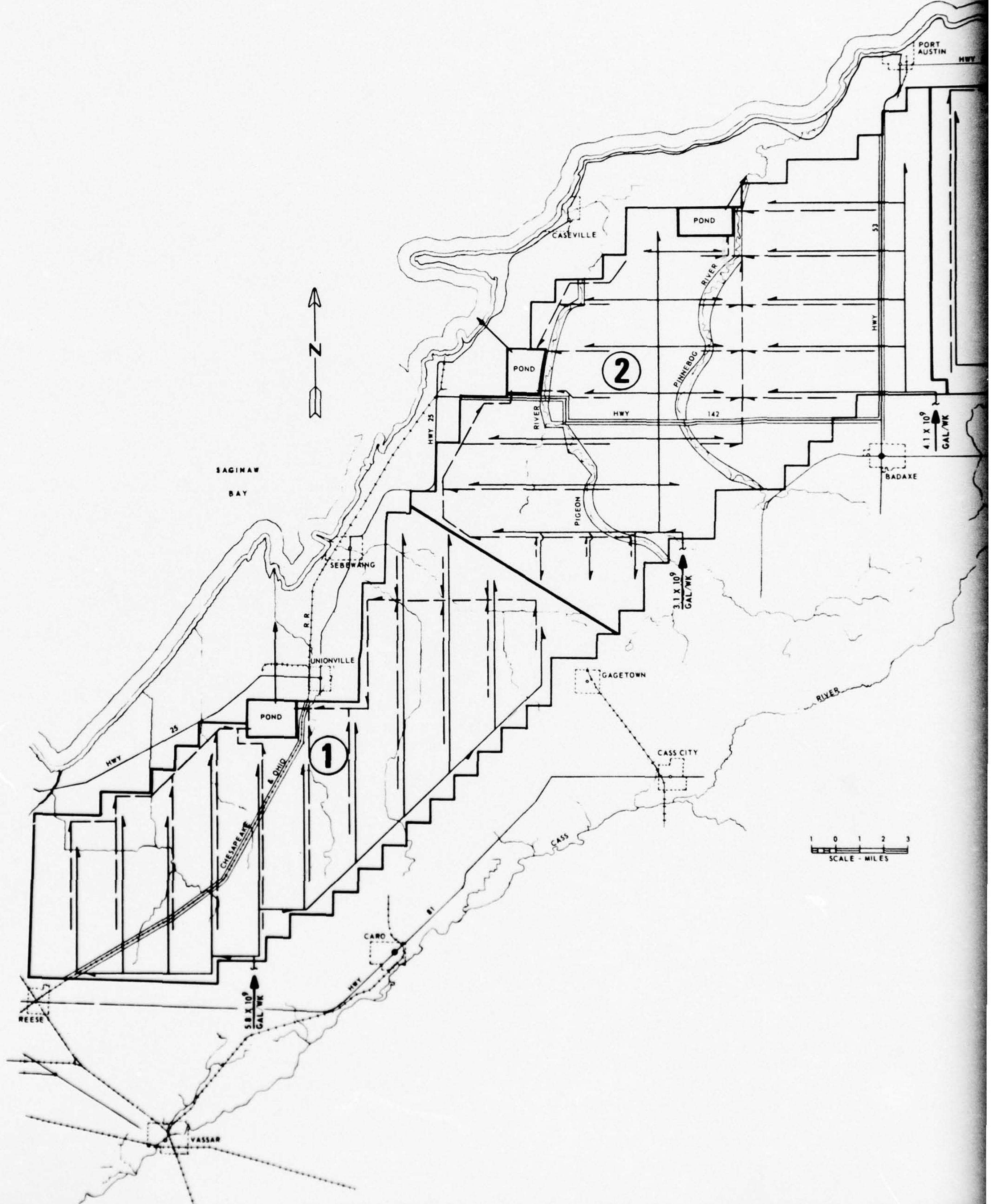


FIGURE VI-3
WASTEWATER TREATMENT DESIGN
ST. CLAIR SITE

2

along the Belle River, west of Memphis; the middle subarea is located between the Belle River and Mill Creek, north of Memphis; and the north subarea is located between Mill Creek and the Black River, east of Yale. The middle and north subareas are approximately the same size. The south subarea is about two-thirds the size of the other two areas. The irrigation water inlet is located on the north side of the southern subarea and the west sides of the other two areas. The south subarea has a discharge point on the Belle River, the middle subarea discharges into Mill Creek and the north subarea has two discharge points into the Black River. The combined weekly capacity of these subareas is 7.1 billion gallons or the equivalent of 681 MGD on an annual basis (Table VI-1).

The Huron-Tuscola site (Figure VI-4) is the largest of the five sites chosen. It is divided into three subareas of approximately equal size. The sites are located generally northwest and north of the Cass River basin. The irrigation water inlets are all located on the south sides of the subareas. The discharge points from the holding ponds are into Saginaw Bay or directly to Lake Huron. The southern subarea has a treatment capacity of 5.8 billion gallons per week, the middle subarea 7.2 billion gallons per week, and the eastern subarea 6.1 billion gallons per week. The combined treatment capacity is 19.1 billion gallons per week or an equivalent daily rate of 1832 MGD (Table VI-1).



PORT AUSTIN
HWY
CASEVILLE
POND
POND
POND
RIVER
PINNEBOG
RIVER
HWY
142
HWY 25
HWY
53
2
1
N
SAGINAW
BAY
PIGEON
BADAXE
4.1×10^9 GAL/WK
3.1×10^9 GAL/WK
5.8×10^9 GAL/WK
SEBEWAING
R R
UNIONVILLE
GAGETOWN
CASS CITY
RIVER
CASS
HWY
25
CHESAPEAKE & OHIO
CARO
81
HWY
REESE
VASSAR
1 0 1 2 3
SCALE - MILES

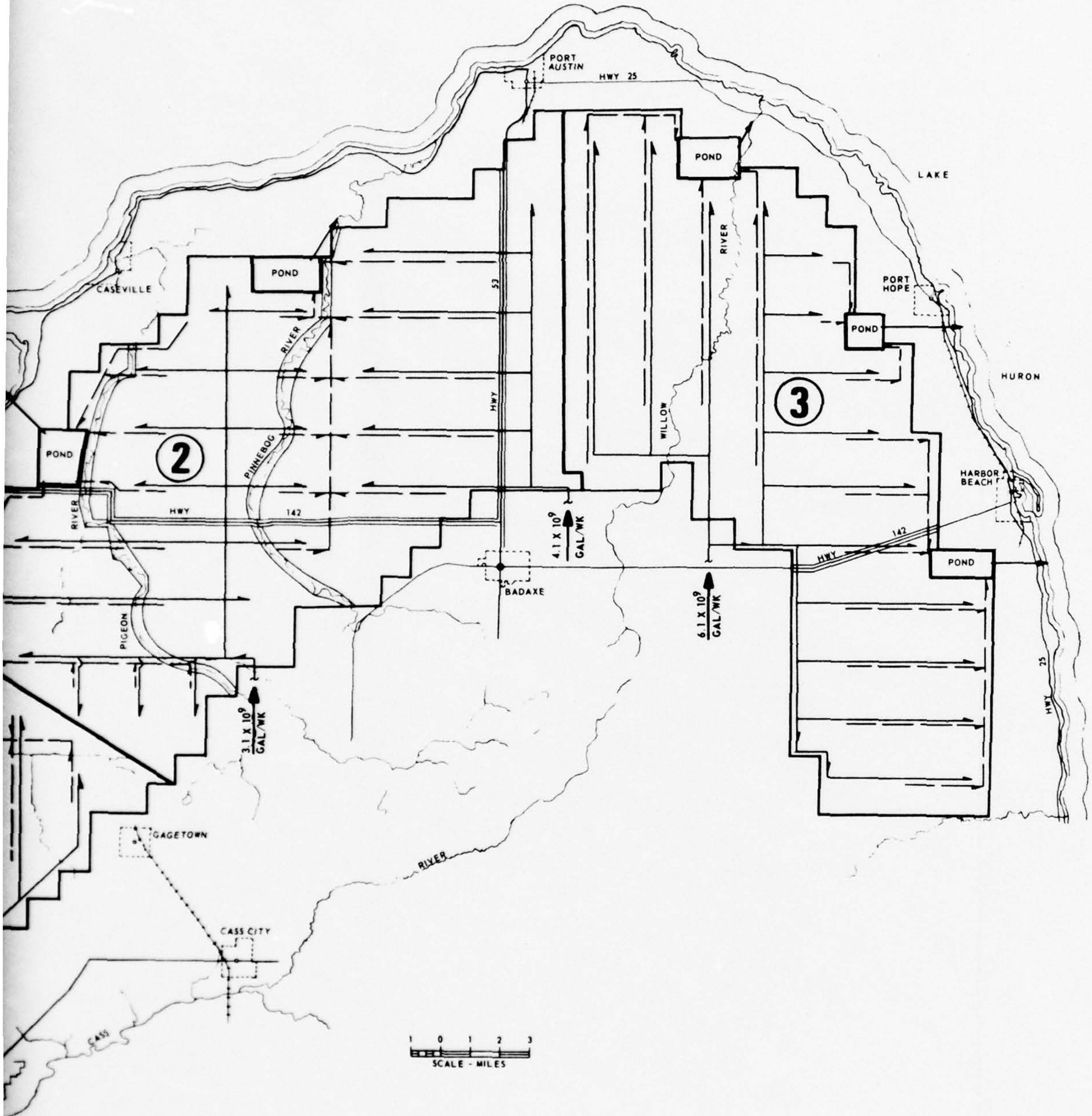


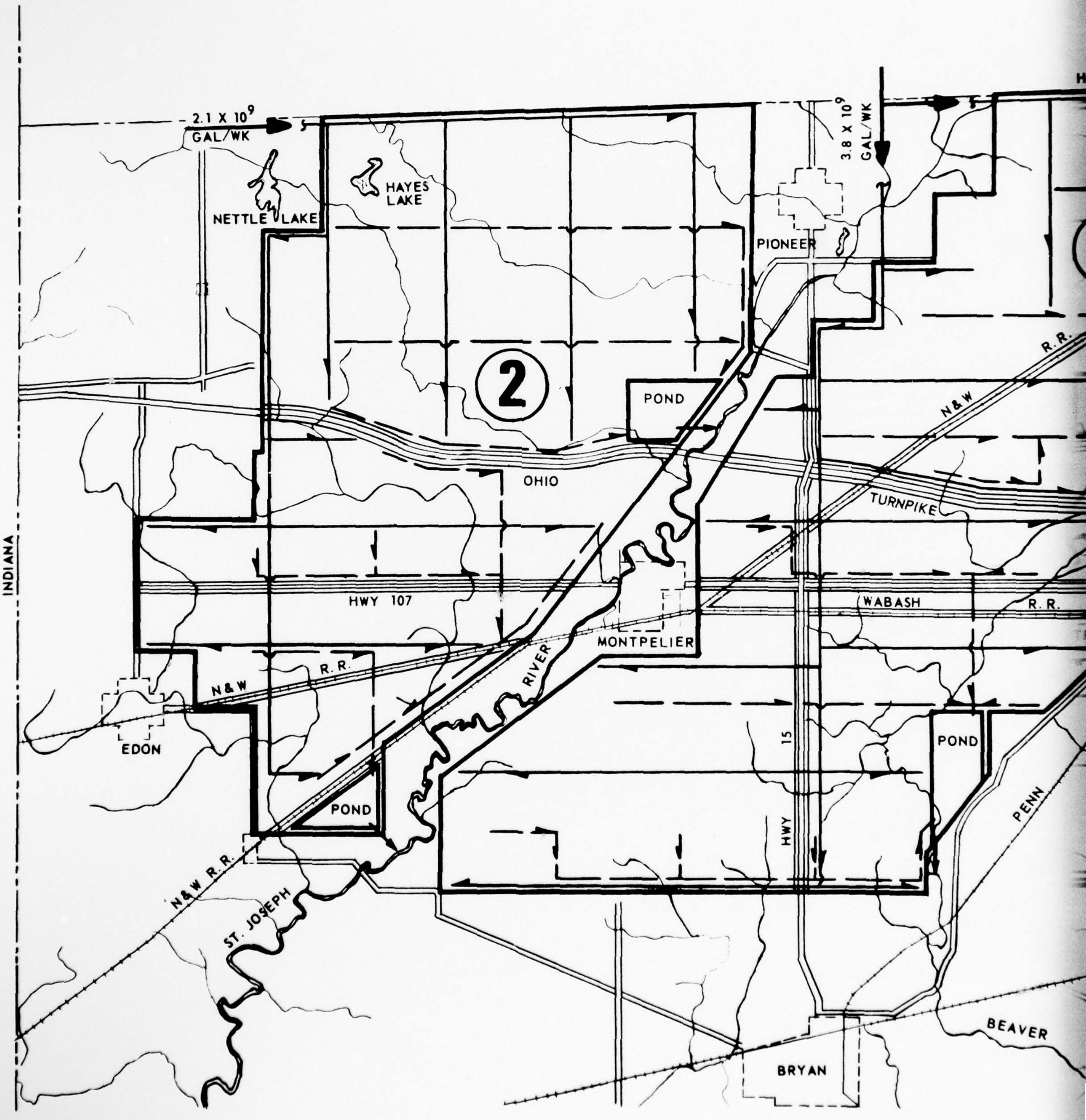
FIGURE VI-4
WASTEWATER TREATMENT DESIGN
HURON-TUSCOLA SITE

2

The Fulton-Williams site (Figure VI-5) is located in Ohio on the St. Joseph River. This is the only site that was designed for the graded border concept of applying the irrigation water. The site is divided into two subareas, one east of the river and the other west of the river. The northern edge of both subareas is the Ohio-Michigan boundary. The irrigation inlet points are located on the northwest corners of each subarea. Both subareas have two discharge points. The western subarea discharges into the St. Joseph River and the eastern subarea discharges into the Tiffin River. This site is criss-crossed by several major highways, one of which is the Ohio Turnpike. The graded border method of applying the irrigation water is better suited for irregular sites than the center pivot system. The combined capacity of this site is 5.9 billion gallons per week or 566 MGD.

Renovated Water Discharge Quantity

The quantity of renovated water discharged from the irrigation sites is approximately equal to the quantity of irrigation water applied. This design assumption is based on the following accounting of water applied and lost. Annual application of 70 inches of irrigation water plus approximately 31 inches (81) of rainfall equals a total application of 101 inches. Evapotranspiration loss of approximately 27 inches (84) leaves a balance of 74 inches of water. Allowing for some loss by deep percolation leaves approximately 70 inches per year to be discharged through the reuse ponds.



2.1 X 10^9 GAL/WK
3.8 X 10^9 GAL/WK
HAYES LAKE
NETTLE LAKE
PIONEER
2
POND
OHIO
TURNPIKE
N & W
R.R.
INDIANA
HWY 107
WABASH
MONTPELIER
RIVER
N & W R.R.
EDON
POND
HWY 15
PENN
N & W R.R.
ST. JOSEPH
BEAVER
BRYAN

1

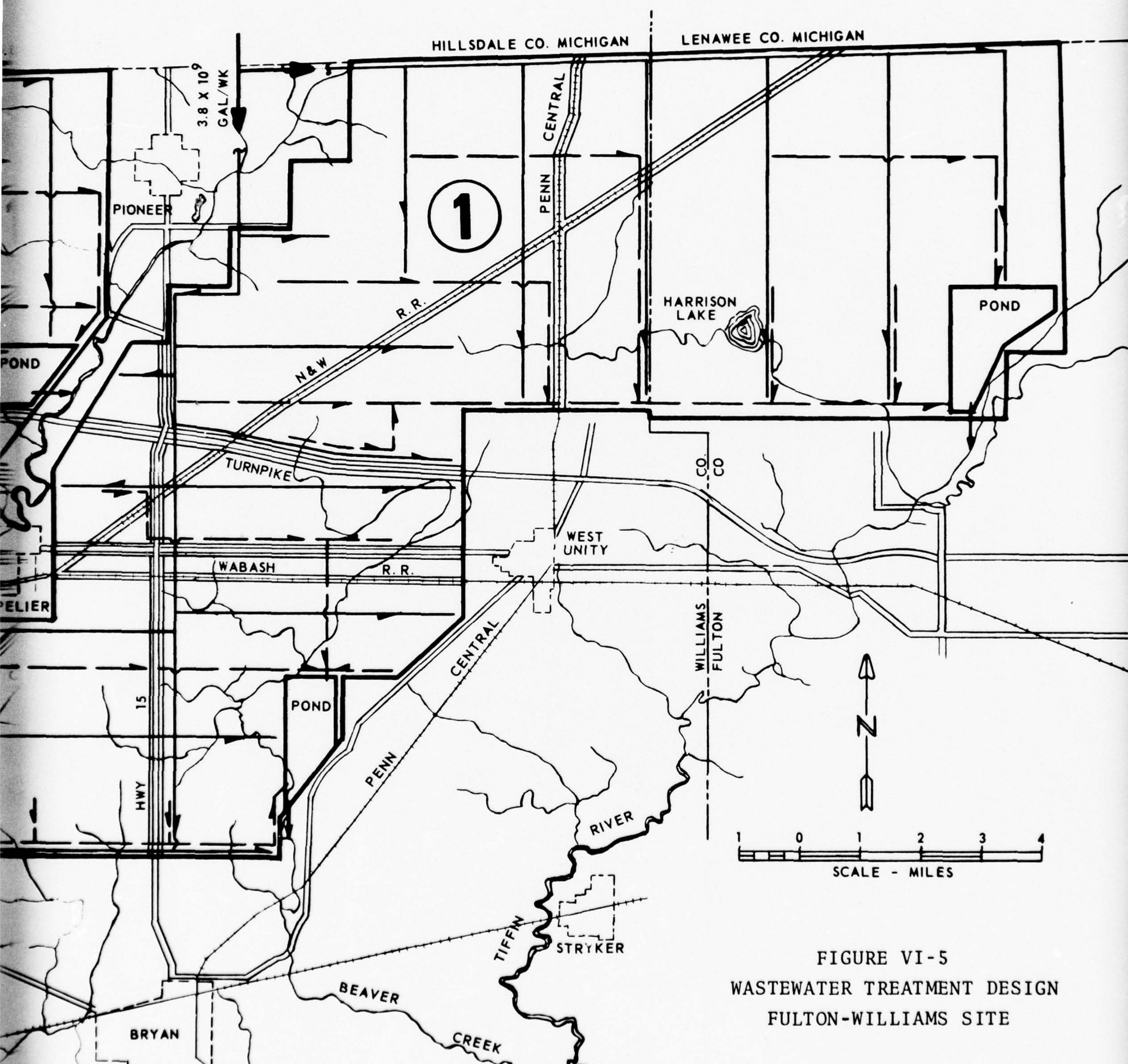


FIGURE VI-5
WASTEWATER TREATMENT DESIGN
FULTON-WILLIAMS SITE

2

The reuse storage pond pumps and the storage pond capacities have been designed for a short period flow equivalent to three inches per week discharge instead of the average of two inches per week indicated above.

Design Reliability

Overall system reliability has been designed into the proposed land treatment concept. From the entry into the irrigation site to the discharge of the renovated water, alternate and backup systems have been provided at critical points.

The main transmission system for handling the incoming irrigation water is based on gravity flow in open canals. The first major point requiring "man-supplied" power is the irrigation module pump station. Reliability at this point is provided by spare pump capacity, looped electrical power supply, an irrigation system hydraulically designed to handle 50% more than the average design application rate, and a design concept that limited the size of a single module. The irrigation system is designed to apply three inches of wastewater per week, but the planned average application rate is two inches per week. This hydraulic overdesign is necessary to make up wastewater applications due to prolonged rainy weather, wet spring or fall seasons, and crop planting and harvesting periods. The temporary loss of a single module will have little effect on the overall reliability of a system.

Within a single irrigation module, the wastewater is distributed through 16 irrigation rigs. Each rig is individually controlled and powered through underground conduit runs. Having many essentially identical rigs simplifies the stocking and availability of spare parts.

The flow of the water after it reaches the soil surface module is controlled by gravity. The water percolates vertically downward to the tile underdrain laterals, then by submains and mains to the lower edge of an irrigation module. The collected percolate is lifted by low-head pumps into gravity-flow open canals. This is the second point at which "man-supplied" power is required. Reliability is again provided by spare pump capacity, looped electrical power supply, and if needed, mobile diesel-powered emergency pumps.

The renovated water flows by gravity through open canals to the reuse storage pond pump station. This is the third point where "man-supplied" power is required. Reliability at this pump station is particularly important. The collected renovated water is lifted from the collection canals into the reuse storage ponds. Reliability is provided by spare pumps, looped electrical power supply, and auxiliary, automatic starting, diesel power units.

The reuse storage pond provides reliability with at least six to 10 days storage capacity. Even greater capacity can be provided if a particular location would require it. Flow from the storage pond to the discharge points is by gravity flow.

Aesthetics

The visual impact of the land treatment sites on the general public is of prime concern. The interface with the public will be at the perimeter of the sites or along highway or river corridors that will cross the sites. Generally what the public will see is a giant farming operation. Buffer strips will provide a transition zone between this giant farming operation and adjacent property. Pumping stations will have low profiles and can be attractively landscaped to blend with the general farm scene.

The most striking view of a land treatment site will be from the air. To a certain extent, some of the square checker board pattern presently established by the section roads will still exist. The most common description of eastern Colorado, where giant center pivot irrigation rigs are used, is that it looks like a series of "large green lily pads floating on a brown lake."

Reuse storage ponds can be built with irregular, "natural lake" shorelines and the discharge canals can be made to look more like natural streams than manmade canals.

Construction Schedule

The overall construction schedule for the land treatment project can be quite flexible. As shown in

Figure VI-6, the project can be divided into 11 construction areas. Each of these 11 areas represents a complete treatment site. The sites and subareas are shown in previous figures.

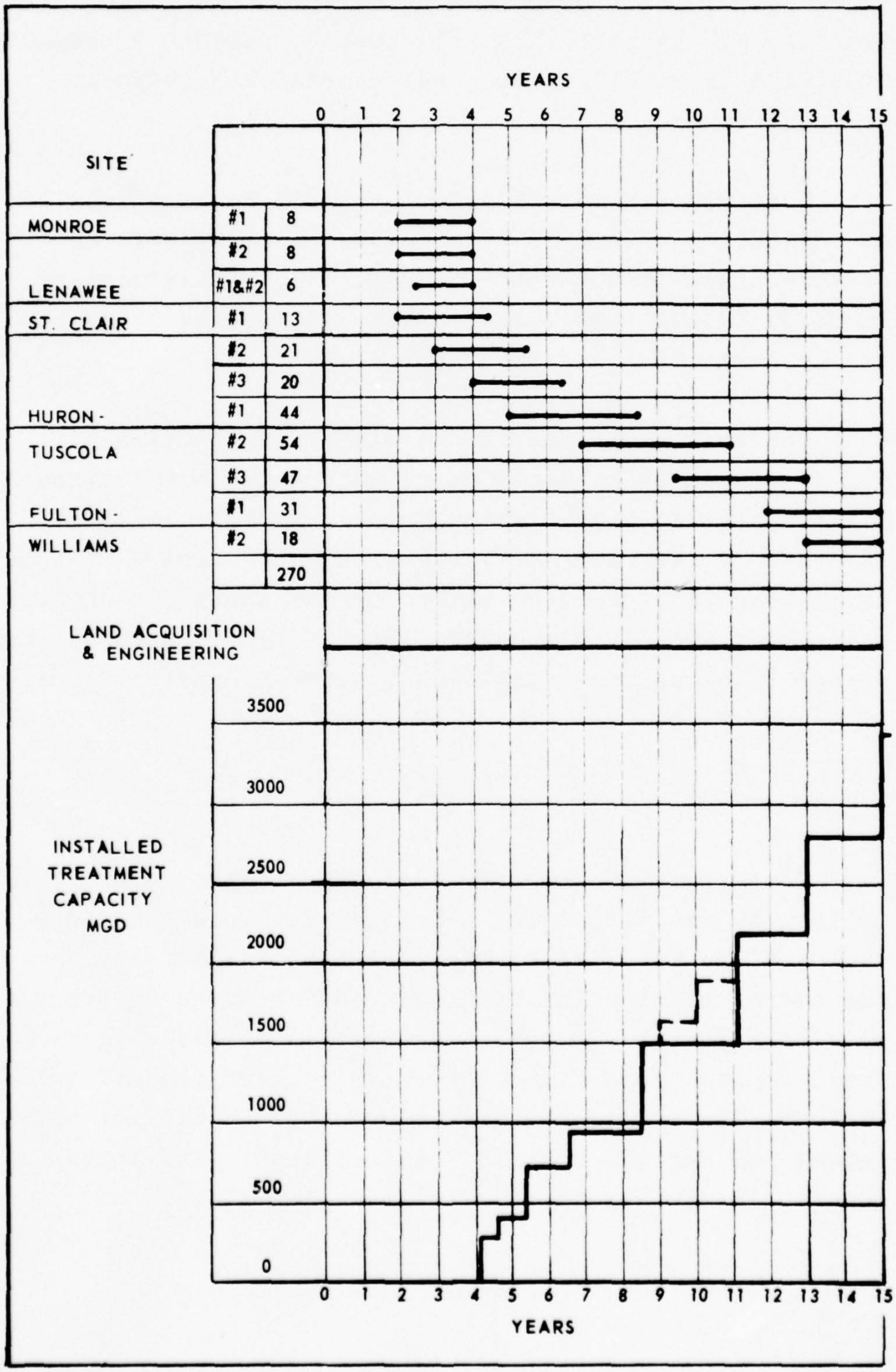
Construction crowding does not represent a restraint on scheduling. Some of the factors that may set the overall schedule are need for capacity, acquisition of land, available funds, and construction schedule of sewage collection and treatment projects.

The on-stream capacity within a construction site can be scheduled by first constructing the major transmission canals, pump stations, reuse storage facilities, and outfall structures. Irrigation and drainage modules could then be brought on-stream as the construction work is completed on each module. This is represented by the dashed lines on the "Installed Treatment Capacity" curve of Figure VI-6.

COSTS

Costs for the components of the Irrigation and Collection facilities are tabulated for each site in Tables VI-2, VI-3, VI-4, VI-5, VI-6. Additionally, the energy requirement is displayed for those components requiring power. Costs are summarized in Table VI-7. Total capital cost for all five sites plus project administration and laboratory is about $1.68 billion and annual O&M costs are about $69.7 million. The total annual cost is about $169 million. Annualized cost

Figure VI-6
CONSTRUCTION SCHEDULE



is the sum of the annual O&M (includes replacement costs) and the annual capital recovery (amortization and interest). The capital recovery in Table VI-7 is based on 50 year life and 5.5% interest rate. Costs per million gallons of wastewater treated are: $1,367 for capital, $57 for annual O&M, $80 for annual capital recovery, and $137 for total annualized costs. If the interest rate is increased from 5.5% to 7% or 10%, the total annualized costs become $155 and $193, respectively (Table VI-8). This assumes same capital data, but replacement factors and capital recovery factors were calculated at 7% and 10% interest rate to show the significant effect of this variable.

Table VI-2
Costs for Monroe Site
(M$ = 1000)

	Unit	Unit Cost ($)	Capital Cost (M$)	O&M (M$/Yr)	Energy (MWH/Yr*)
Land					
Acquisition	41,040 Ac	1,084	44,487		
Family Relocation	1,391 Fam	5,000	6,955		
Legal Adm. + 10%			5,144		
Woodland Clearing	2,520 Ac	380	958		
Site Preparation	41,040 Ac	100	4,104		
Transmission					
Clay Lined Channels	42.4 Mi	42,400	1,798	18	
Irrigation Method					
Center Pivot-95%	16 Mod	1,461	23,376	2,469	784,000
Runoff Control-Land Cells	16 Mod	77	1,232	203	
Drainage					
33 ft Lateral Spacing	16 Mod	1,675	26,800	797	15,000
Reuse					
Pumping	6,750 HP	80	540	513	40,000
Unlined Channels	34.2 Mi	16,560	566	5.7	
Storage Facilities	1.6 Sq Mi	1,200	1,920	19.2	
Outfalls					
Unlined Channels	0.6 Mi	40,000	24	.2	
Outfall Structures	2 ea	20,000	40	.4	
Observation Wells	4,400 Ft	8	35	.4	
Upland Ditches for Surface Water Collection	22 Mi	15,000	330	3.3	
General Site					
Electrical	16 Mod	100	1,600	46	
Field Service Buildings	16 Mod	5,400	86	5	
Site Administration	1 Site	102	102	202	
TOTAL			120,097	4,282	

*MWH/Yr = megawatt hours per year

Table VI-3
Costs for Lenawee Site
(M$ = 1000)

	Unit	Unit Cost ($)	Capital Cost (M$)	O&M (M$/Yr)	Energy (MWH/Yr*)
Land					
Acquisition	18,300 Ac	960	17,568		
Family Relocation	305 Fam	5,000	1,525		
Legal Adm. + 10%			1,909		
Woodland Clearing	1,010 Ac	380	384		
Site Preparation	18,300 Ac	70	1,281		
Transmission					
Clay Lined Channels	19.8 Mi	42,400	840	8	
Irrigation Method					
Center Pivot-95%	6 Mod	1,461	8,766	926	300,000
Runoff Control-Land Cells	6 Mod	100	600	90	
Drainage					
33 ft Lateral Spacing	6 Mod	1,675	10,050	299	6,000
Reuse					
Pumping	2,710 HP	80	217	206	16,000
Unlined Channels	13.6 Mi	16,560	225	2	
Storage Facilities	0.6 Sq Mi	1,200	720	7	
Outfalls					
Unlined Channels	0.9 Mi	40,000	36	.4	
Outfall Structures	3 ea	20,000	60	.6	
Observation Wells	2,400 Ft	8	19	.2	
Upland Ditches for Surface Water Collection	10 Mi	15,000	150	1.5	
General Site					
Electrical	6 Mod	100	600	18	
Field Service Bldgs.	6 Mod	5,400	32	2	
Site Administration	1 Site	100	102	155	
TOTAL		45,084	1,716		

*MWH/Yr = megawatt hours per year

Table VI-4

Cost for St. Clair Site

(M$ = 1000)

	Unit	Unit Cost ($)	Capital Cost (M$)	O&M (M$/Yr)	Energy (MWH/Yr*)
Land					
Acquisition	149,220 Ac	611	91,173		
Family Relocation	2,130 Fam	5,000	10,650		
Legal Adm. + 10%			10,182		
Woodland Clearing	14,200 Ac	380	5,396		
Site Preparation	149,220 Ac	45	6,715		
Transmission					
Clay Lined Channels	112 Mi	42,400	4,749	47	
Irrigation Method					
Center Pivot-95%	54 Mod	1,461	78,894	8,332	2,646,000
Runoff Control-Land Cells	54 Mod	100	5,400	810	
Drainage					
33 ft Lateral Spacing	54 Mod	1,675	90,450	2,690	50,000
Reuse					
Pumping	23,090 HP	80	1,847	1,756	133,000
Unlined Channels	116 Mi	15,560	1,920	19	
Storage Facilities	5.3 Sq Mi	1,200	6,360	64	
Outfalls					
Unlined Channels	1.9 Mi	40,000	76	.8	
Outfall Structures	4 ea	20,000	80	.8	
Observation Wells	9,000 Ft	8	72	.7	
Upland Ditches for Surface Water Collection	10 Mi	15,000	150	1.5	
General Site					
Electrical	54 Mod	100	5,400	156	
Field Service Buildings	54 Mod	5,400	292	16	
Site Administration	1 Site	102	102	272	
TOTAL		319,908	14,166		

*MWH/Yr = megawatt hours per year

Table VI-5
Costs for Huron-Tuscola Site
(M$ = 1000)

	Unit	Unit Cost ($)	Capital Cost (M$)	O&M (M$/Yr)	Energy (MWH/Yr*)
Land					
Acquisition	388,970 Ac	664	258,276		
Family Relocation	5,298 Fam	5,000	26,490		
Legal Adm. + 10%			28,476		
Woodland Clearing	23,200 Ac	380	8,816		
Site Preparation	388,970 Ac	45	17,504		
Transmission					
Clay Lined Channels	302 Mi	59,000	17,818	178	
Irrigation Method					
Center Pivot-95%	145 Mod	1,461	211,845	22,374	7,105,000
Runoff Control-Land Cells	145 Mod	100	14,500	2,175	
Drainage					
33 ft Lateral Spacing	145 Mod	1,675	242,875	7,221	134,600
Reuse					
Pumping	62,500 HP	80	5,000	4,750	363,000
Unlined Channels	275 Mi	18,000	4,950	50	
Storage Facilities	14.5 Sq Mi	1,200	17,400	174	
Outfalls					
Unlined Channels	6.6 Mi	40,000	264	2.6	
Outfall Structures	6 ea	20,000	120	1.2	
Observation Wells	13,400 Ft	8	107	1.1	
Upland Ditches for Surface Water Collection	33 Mi	15,000	495	5	
General Site					
Electrical	145 Mod	100	14,500	420	
Field Service Buildings	145 Mod	5,400	783	44	
Site Administration	1 Site	102	102	407	
TOTAL		870,321	37,803		

*MWH/Yr = megawatt hours per year

Table VI-6

Costs for Fulton-Williams Site

(M$ = 1000)

	Unit	Unit Cost ($)	Capital Cost (M$)	O&M (M$/Yr)	Energy (MWH/Yr*)
Land					
Acquisition	114,000 Ac	677	77,178		
Family Relocation	2,987 Fam	5,000	14,935		
Legal Adm. + 10%			9,211		
Woodland Clearing	15,680 Ac	380	5,958		
Site Preparation	114,000 Ac	45	5,130		
Transmission					
Clay Lined Channels	144 Mi	53,070	7,642	77	
Irrigation Method					
Graded Border	49 Mod	2,150	105,350	6,615	2,400,000
Drainage					
33 ft Lateral Spacing	49 Mod	1,675	82,075	2,440	45,500
Reuse					
Pumping	21,100 HP	80	1,688	1,604	122,000
Unlined Channels	106 Mi	16,560	1,755	18	
Storage Facilities	4.9 Sq Mi	1,200	5,880	59	
Outfalls					
Unlined Channels	1.2 Mi	40,000	48	.5	
Outfall Structures	4 ea	20,000	80	.8	
Observation Wells	6,800 Ft	8	54	.5	
Upland Ditches for Surface Water Collection	36 Mi	15,000	540	5.4	
General Site					
Electrical	49 Mod	10	490	14	
Field Service Buildings	49 Mod	5,400	265	15	
Site Administration	1 Site	102	102	271	
TOTAL			322,791	11,120	

*MWH/Yr = megawatt hours per year

Table VI-7

Summary of Capital and Annualized Costs
All Sites

Site	Capital ($ in 1000)	O&M ($ in 1000)	Capital Recovery ($ in 1000)	Total Annual Costs ($ in 1000)
Monroe	120,097	4,282	7,093	11,375
Lenawee	45,084	1,716	2,663	4,379
St. Clair	319,908	14,166	18,894	33,060
Huron-Tuscola	870,321	37,803	51,401	89,204
Fulton-Williams	322,791	11,120	19,064	30,184
Project Admin. & Labor	610	610	36	646
TOTAL	1,678,811	69,697	99,151	168,848

Annual wastewater application of 1228 x 10^9 gal.

Cost per million gallon wastewater treated (Dollars/MG)	1,367	57	80	137

Table VI-8

Summary of Capital and Annualized Costs at 7% and 10% Interest Rates
($ in 1000)

		7% Interest			10% Interest		
Site	Capital	O&M	Capital Recovery	Total Annual Cost	O&M	Capital Recovery	Total Annual Cost
Monroe	12,097	4,223	8,702	12,925	4,142	12,118	16,260
Lenawee	45,084	1,694	3,267	4,961	1,663	4,549	6,212
St. Clair	319,908	13,972	23,181	37,153	13,694	32,279	45,973
Huron-Tuscola	870,321	37,284	63,063	100,347	36,538	87,815	124,353
Fulton-Williams	322,791	10,957	23,389	34,346	10,715	32,570	43,285
Project Admin. & Labor	610	609	44	653	607	62	669
TOTAL	1,678,811	68,739	121,646	190,385	67,359	169,393	236,752

Annual wastewater application of 1228 x 10^9 gal.

Cost per million gallons waste-water treated (Dollars/MG)	1,367	56	99	155	55	138	193

SECTION VII
CROPPING SYSTEMS AND FARM OPERATION

CLIMATE

The Southeastern Michigan area has a climate characterized by a mean annual temperature at Detroit of 49°F, ranging from a mean high of 73°F in July to a low of 25°F in January. Temperature extremes of 105°F and -24°F are recorded (81). The growing season (mean length of freeze-free period) ranges from about 150 days in the northern parts to 180 days near the Ohio border (22). Mean monthly temperatures are above 32°F at Detroit from March through November (81).

Average annual precipitation for Southeastern Michigan varies from 28 to about 34 inches, spread rather uniformly throughout the year (81). During the growing season, an average of about 0.7 inches precipitation occurs each week. Average annual precipitation exceeds the average potential loss from evapotranspiration by 5-10 inches (84).

CROP SELECTION AND NUTRIENT REMOVAL

The basic function of the cropping system is to provide for continued renovation of the wastewater applied as frequent irrigations on the land treatment site. This can only be accomplished on a long term basis if the chosen crops can remove nutrients fast enough to prevent rapid accumulation of toxic nutrient

levels in the soil. The economic value and use of the crop is of interest, but a less important concern. Farm operations are dictated by the crops selected and the desired use of the crops.

The CRREL Report (82) summarizes the nutrient uptake capability of various crops (Table VIII-1). This information indicates that grass crops and the deep rooted legumes use relatively large amounts of the various plant nutrients. The three crops, alfalfa, corn, and reed canarygrass, account for the greatest uptake of all the nutrients. The potassium uptake of potatoes is an exception, but only if the tops are harvested, which presents a utilization or disposal problem.

Crop Rotation

A given selected crop could be used continuously for a few years and should remove its expected amounts of nutrients as long as the crop remained vigorous. However, long continuous use of one crop often encounters a buildup of problems (disease, insects, weeds, etc.) peculiar to that crop. Such problems could reduce the stand and vigor enough that nutrient removal would no longer be satisfactory. Crop rotation has long been recognized as a means of combatting such problems.

Another reason for using a rotation of crops relates to the overall removal of nutrients. Different crops remove different amounts of the various plant nutrients and other wastewater elements (82). Thus, a

Table VII-1

Uptake of Various Elements by a Sampling of Agricultural Crops (lb/acre).

[Reproduced from CRREL Report (82)]

Plant part	*N*	*P*	*S*	*B*	*K*	*Ca*	*Na*	*Mg*	*Fe*	*Mn*	*Zn*	*Cu*
Corn												
Grain	95	16	9	0.2	15	2	7	9	0.17	0.45	0.28	0.017
Stalks	60	9	10	0.2	37	19		14	1.20	0.96	0.36	0.042
Total	155	25	18	0.4	52	21		23	1.37	1.41	0.64	0.059
Corn grain and stalks	86	17			118							
Wheat												
Grain	52	9.6	4	0.1	10	2	1	3	0.19	0.14	0.12	0.017
Straw	24	3.9	7	0.2	32	10		5	0.50	0.32	0.08	0.014
Total	76	14	11	0.3	42	12		8	0.69	0.46	0.20	0.031
Wheat grain and straw												
(1)	62	12			37	8						
(2)	50	9.2	7.8		23.9	6.6	2	4.3				
Soybeans												
(1)	113	18	10	0.05	48	26		16	0.63	0.23		0.033
(2)	99	14			40							
Alfalfa												
(1)	155	16	16	0.6	110	120	3	15	0.90	0.48	0.30	0.06
(2)	220	21			110	150						
Red clover												
(1)	126	13	9	0.22	80	92	4	22	1.02	0.6	0.25	0.1
(2)	120	12			81	76						
Reed canary												
(1)	98	10.9		9.4		69.1	64.4	3.8	17			
(2)	226	36										
Potatoes												
Tuber and Tops	200	8	10.4		220	52		16.3				0.028
Tuber and Tops	80	16			120	31						
Tuber	46	9.4	2.7		63.5	2.4	2.8	3.8				

rotation of crops helps maximize the long term continuous removal of all nutrients applied to land treatment sites.

Table VII-2 outlines the four component parts of the crop rotation chosen for wastewater irrigation sites. The four cropping components are presented in the sequence of their occurrence in the crop rotation. The harvest and use alternatives indicate the variety of possibilities available in utilizing this crop rotation.

Alfalfa and red clover are relatively heavy users of K, Ca, N, P, S, Mg, B, Fe, Zn and Cu. Innoculation of alfalfa for nodulation should be omitted to encourage more N uptake from the soil and discourage fixation of atmospheric N_2 (although nodule forming bacteria are often present in the soil depending how long it has been since alfalfa was grown).

Corn uses relatively large amounts of the same nutrients as the legumes except less Ca is used. Corn takes up somewhat more Mn and Zn. Forage sorghums could be substituted for corn but generally are not as well adapted and have less attractive use potential than corn (33,83). Sorghums are planted later than corn and could be considered as an emergency replacement for corn with green chop use opportunities (35). Sorghum-sudangrass hybrids appear to be the best yielding sorghum types for Michigan (34).

Reed canarygrass is outstanding for its use of N, P and B. It is the only crop shown to remove sizable

Table VII-2

CROPPING SYSTEM ALTERNATIVES

Crop Rotation Components	Harvest Alternatives	Use Alternatives
A. Alfalfa-smooth bromegrass (Alfalfa could be grown alone. Timothy could be added to the alfalfa-brome mixture or substituted for bromegrass.)	Field chop ("greenchop")	Commercial dehydrator
		Pellets, meal, and special products
		Silage
	Cut, swath & delayed field chop	Dehydrator
		Pellets, meal, etc.
		Silage
		Hay cubes (thru dryer first)
	Cut, swath & field cure	Hay cubes
		Baled hay

Table VII-2 (Contd.)

Crop Rotation Components	Harvest Alternatives	Use Alternatives
B. Alfalfa-bromegrass-corn (Forage sorghums could be substituted for corn but with fewer use alternatives.)	Field chop at physiological maturity	Silage
		Dehydrator-pellets, etc.
	Field cut at physiological maturity	High-moisture shelled corn
		High-moisture ground ear corn
		Dried shelled corn
		Silage (alfalfa grass, stover)
	Field combine after field dried	Shelled corn
		Dry stover mixed with green grass-legume hay
C. Alfalfa-brome-red clover (Timothy could be added or substituted for brome.)	(Same alternatives as for alfalfa-bromegrass)	
D. Reed Canarygrass	(Same alternatives as for alfalfa-bromegrass)	

All necessary field operations are expected to be contracted out, including harvesting and removal of crops.

amounts of Na and Fe. It is well adapted to wet sites, very productive and is a palatable, nutritive forage grass (30,51,54). Reed canarygrass makes good grass silage with a protein content approaching 17%, if cut early. This is comparable to alfalfa. The palatability and protein content are both very good if grass height is not allowed to exceed 12 inches before cutting. At this early stage, field chopping and dehydrating to pellets, meal or other products would provide a good source of protein for the feed industry. When harvested for hay, reed canarygrass usually is allowed to reach the early seed head stage before cutting. Tonnage is greater but the protein content drops to 10-12% and palatability is reduced.

Smooth bromegrass is a productive, palatable, well-adapted perennial grass for southern Michigan. It is widely used in combination with legumes, especially alfalfa (37,51,54). Grass-legume mixtures should provide the best prospects for maximum removal of a wide range of nutrients. Timothy is a palatable forage grass that could be a second choice alternate to replace bromegrass or supplement the grass-legume mixtures (34,37). Reed canarygrass is too aggressive to use compatibly with a legume such as alfalfa or red clover.

Crop Removal of Nutrients from Wastewater

The selected cropping system includes a mix of crops that provide a broad base of general renovative capabilities. However, this cropping system will likely

not remove the full quantity of nutrients contained in the wastewater. Table VIII-3 compares the expected nutrient application with nutrient removal by crops. Nutrient application is based on 70 inches of typical wastewater containing the concentrations as earlier shown in Table I-1. Twelve of the commonly recognized 16 essential elements for plant growth are considered. Carbon, hydrogen, oxygen, and molybdenum are omitted. The estimates for crop removal in Table VII-3 represent the ranges of uptake for corn, alfalfa, red clover, and reed canarygrass as shown earlier in Table VIII-2. Crop uptake of nutrients depend on many variables such as soil, fertility of land, soil moisture, climate, diseases, crop, etc. Thus, values for crop removal in Table VII-3 are used only to show magnitudes. The nutrients applied in the wastewater but not removed by the crops will be either retained in the soil or discharged into the tile drainage water or groundwater.

The cropping system removes only a portion of the total nitrogen applied in the wastewater. Nitrogen not removed by the crops is expected to be largely converted to soluble nitrate. Unless this nitrate undergoes denitrification, considerable nitrate-nitrogen will leach through the soil and enter the tile drainage system or groundwater. However, considerable denitrification is expected for the Southeastern Michigan irrigation sites. As much as 30-50% of the applied nitrogen could possibly undergo denitrification.

Phosphorus is expected to be almost completely removed by the soil but only partially utilized by crop

Table VII-3

Crop Removal of Nutrients from Wastewater

Nutrient	Applied in 70" of Typical Wastewater	Crop Removal	Difference
	lb/acre/year		
Nitrogen	315	86 - 226	81 - 229
Phosphorus	157	12 - 36	121 - 145
Copper	1.4	0.06 - 0.1	∿1.3
Iron	1.4	1.3 - 17	-
Manganese	3.2	0.48 - 1.41	1.8 - 2.7
Zinc	3.2	0.25 - 0.64	2.6 - 3.0
Boron	10.5	0.22 - 9.4	1.1 - 10.3
Chloride	1575	-	<1575
Sulfur (as sulfate)	1960	27 - 54	1906 - 1933
Calcium	315*	21 - 150	165 - 294
Potassium	140*	52 - 118	22 - 188
Mangesium	80*	3.8 - 23	57 - 76

*Average values for secondary treated effluent. Taken from Table 3-I of CRREL Report (82).

growth. The phosphorus not removed by cropping is expected to accumulate in the soil at a rate exceeding 100 pounds per year. The soils are expected to be capable of removing and storing phosphorus at this rate for many years.

Copper also will likely accumulate in the soil since very little is used by plants. As long as pH is maintained above 6.5, plants can tolerate as much as 500 ppm in the soil (11). This is equivalent to approximately 500 pounds of copper per acre in the surface three inches of soil. With proper pH management, the annual application of 1.4 pounds copper per acre should pose no short term crop toxicity problems. Essentially all the iron contained in the applied wastewater should be removed by the crops.

Manganese will likely accumulate in the soil since average annual crop use of this element accounts for less than half of the amount delivered in the wastewater. If the pH is maintained above 5.5, crops will tolerate more than 2 ppm in the soil solution. This would be 10 times the manganese concentration in the applied wastewater but some concern is justified relative to the eventual accumulation of crop toxic levels.

Zinc is also retained by the soil and will accumulate since more is applied than can be utilized by the crops. If the soil pH is kept above 6.5 it is possible that crops will tolerate more than 2000 pounds zinc per acre (11). Even without crop removal, it would take many years to accumulate phytotoxic levels in the soil. The amount of time elapsed before phototoxic accumulations are reached is uncertain.

Boron also occurs as a soluble salt that passes through the soil with the drainage water. Reed canarygrass appears to be capable of removing most of the boron contained in the wastewater that is applied during the growing season. When other crops in the rotation system are present, most of the boron should pass through with the drainage water. Consistent leaching and removal of excess boron will be important since it could otherwise accumulate to a phytotoxic level in the soil.

Chlorides, sulfates, calcium, potassium, and magnesium are supplied in much greater quantity than crops can be expected to use. Since these salts are soluble and not retained by the soil, they will largely pass through the soil and be discharged through the underdrain. One exception is potassium because of fixation by clay minerals.

FARM OPERATIONS

Rotation of the cropping system over a relatively long period is preferred to minimize the cost of frequent crop changes (tillage and seeding costs). A 10-year rotation is prescribed to meet this objective. The cropping components occurring in the A, B, C, D sequence shown in Table VIII-2 would have rotational

use periods allotted as follows: A-3 years, B-2 years, C-2 years, and D-3 years. An alternative is the use of a 12-year rotation, 3 years for each cropping component. The 10-year rotation is preferred for reasons to be explained.

Farming activities in the crop rotations are summarized in Table VII-4. The rotations would begin the same with three years of alfalfa-bromegrass. The fourth year, field corn is planted into the established alfalfa-bromegrass sod using "no-tillage" practice (25,47,49,66). Herbicides would be applied in a narrow band over the row as the corn is planted, preferably using a 40-inch row spacing. Only the soil in the corn row is disturbed during the one-trip planting operation. Herbicide spraying is done mainly to control vegetation in the seeded rows. This decreases plant competition with the corn to help it become established. The fifth year, corn is again seeded using "no tillage;" however, the corn rows are planted midway between previous rows.

The sixth year of the 10-year rotation, red clover is seeded with limited tillage and disturbance of existing alfalfa-bromegrass. The use of a range-type drill could be the easiest approach. A light discing

Table VII-4

Summary of Farm Operations Using 10 or 12-Year Rotations of the Cropping System* Described in Table VII-1

Time of Year	Sequence of Activities	Approx. Custom Rate ($/Acre)**
	A. Alfalfa-bromegrass	
Apr. (or Aug) (Planting year only)	Planting (including seedbed preparation) Plow ($8/A) Disc ($4/A) Drag harrow ($3/A) Planting & seed ($10/A)	$25
Spring	Aerial spraying (including insecticide)	$6
Spring to Fall	Harvesting 3 times/season Alternative methods: Field chopping ($18/A) Mowing & Conditioning ($4/A) Baling ($8/A) Cubing ($12/A)	***
	B. Alfalfa-bromegrass-corn	
Early May	Corn planting ("no-tillage" method), including seed, herbicides and insecticides	$13
Summer	Aerial spraying (including insecticide)	$6
Aug. to Oct.	Harvesting (staggered dates) Alternative methods: Field chopping ($18/A) Combining ($12/A) Drying ($.10/bu x 100 bu/A)	***

Table VII-4 (Contd.)

Time of Year	Sequence of Activities	Approx. Custom Rate ($/Acre)*
	C. Alfalfa-bromegrass-red clover	
Apr. (or Aug.) (Planting year only)	Planting red clover	$9
	Disc ($4/A) Planting & seed ($5/A)	
Spring to Fall	Harvesting 3 times/season	***
	Alternatives: Same as (A) Above	
	D. Reed canarygrass	
Apr. (or Aug.)	Planting, inc. seedbed preparation	$16
	Disc twice (2x$4=$8/A) (Late summer-fall and/or spring)	
	Planting & seed ($8/A)	
Spring to Fall	Harvesting 3 times/season	***
	Alternatives: same as (A) above	
Fall (last year in rotation)	Aerial spraying (crop termination with herbicide)	$20

*All crop rotation components are in constant operation and rotation so that at any one time the proportional acreage of each crop system occur as follows:
<u>For 10 year rotation</u>: (A) = 30%, (B) = 20%, (C) = 20%, (D) = 30%
<u>For 12 year rotation</u>: (A) = 25%, (B) = 17%, (B) without corn = 8%, (C) = 25%, (D) = 25%

**Rates for custom operations based on MSU Ext. Bul. E-458 (80). Prices of seed and chemicals based on current market prices for large lot purchases. Local seed dealer was consulted. Crop seeding and chemical treatments were primarily based on MSU recommendations (35,62,63).

***Crops are to be sold as standing in the field. Contractor incurs all harvesting and crop removal costs.

and conventional packer-drill seeding may be adequate. It is assumed that the alfalfa and/or bromegrass vigor may be declining espeically after the competition from two years of corn (37,51). Adding red clover would help restore total forage productivity. If herbicide residue injury to red clover is a problem, then nothing would be planted the sixth year, and the existing alfalfa-bromegrass would be utilized for all or part of one season after corn. This would lead to a longer rotation. Such an extension of the crop rotation probably will not be necessary if a narrow-band (e.g., 4-6 inches), herbicidal treatment is used or if a short residual herbicide is used the second corn year.

Red clover vigor often declines after the second year (51). With this in mind, the plan for the ten-year rotation is to change to reed canarygrass at that time. If the forage productivity of the red clover-alfalfa-bromegrass mixture is still acceptable, the changeover to reed canarygrass can be delayed a year for the longer rotation. It may be necessary to disc twice before seeding the reed canarygrass. One of the best approaches may be to disc in the fall, again the following spring, and then plant. Once the seeding becomes established, reed canarygrass should do very well since it is such a strong competitor.

Near the end of the third season for reed canarygrass, a herbicide is applied to kill the sod in preparation for resuming the following spring with the alfalfa-bromegrass seeding (30). It is anticipated

that plowing will be advisable as part of the seedbed preparation for starting the crop system rotation over again with alfalfa-bromegrass. This would be a logical time to make any necessary land repairs, such as land filling, land leveling, or any major work on the underdrain system.

All stages of the cropping system rotation are expected to be in operation at any one time after the initial start-up period is completed. The simplest way to begin the ten-year rotation would be to start with alfalfa-bromegrass each year for ten years as the site land is developed. The start-up period could be reduced to five years by establishing alfalfa-bromegrass on only half of the newly developed site land and alfalfa-bromegrass-red clover on the remaining area. This would be repeated every year for five years.

During the course of the cropping system rotation, it will be important to maintain control of soil acidity. Liming may be necessary to prevent soil acidity from dropping below pH 6.5. This is necessary to maintain favorable growth conditions for the legumes. It is also important to keep the pH above 6.5 to prevent phytotoxic releases of certain heavy metals such as Mn and Zn.

For planning purposes, the cost of farm operations, exclusive of irrigation operations, is assumed to be about equal to the field value of farm products produced. Some deviation, plus or minus, would be likely

depending on seasonal or climatic variations, market conditions, labor costs, and other unpredictable cropping variables. The cost of irrigation operations are presented elsewhere in this report.

All farm operations are expected to be contracted including disposal of the crops (Table VII-2). By selling the crops as they stand in the field, crop harvesting and removal would be obligations of the contractor. The methods of harvesting and removal should be specified by contract so that control of overall farm operations can be retained.

Preferred crop disposal methods would be those that remove the crop at the earliest possible date with only one pass through the field. Harvesting methods that accomplish this include field chopping or early combining and totally removing high-moisture crops. Less desirable are those practices that involve cutting the crop but leaving it to dry in the field for several hours to several days before removal (56). Such practices could cause annoying delays in irrigation operations and risks partial to complete loss of crop value because of rain damage (40). The least desirable crop removal practice is the one where corn is allowed to go beyond maturity to field dried condition (requiring no artificial drying after harvesting). This practice would consume the entire growing season and accomplish crop removal only one time. The "by-product," dry stover mixed with the green grass-legume forage, would likely have limited utility and create a disposal problem. The field drying period would shut down irrigation operations until the corn was removed.

Crop use alternatives, presented in Table VII-2, provide a feel for the ultimate use possibilities in relation to the various methods of crop removal. Field chop harvesting provides numerous use alternatives. Commercial dehydrators have recently been developing new or specialized products to expand the utility of dehydrated alfalfa (1,4,65). Other forages are also being field chopped and dehydrated, including forage sorghums and grasses more typically thought of as pasture grasses (32,61,77). More recently, dehydration of the whole corn plant has been reported (32). All these products are useful components of specially prepared feeds for livestock.

Field chopping is the conventional method to harvest various crops for silage including corn (36,39), grass-legume mixtures (31,54), forage sorghums (83) and reed canarygrass (54). For continuous silage programs, a recommended practice in Michigan utilizes corn to provide silage from October through May and alfalfa-bromegrass silage ("haylage") for June through September (31).

Harvesting methods involving some field drying after cutting are also used by commercial dehydrators and for silage. By adding portable or stationary artificial drying one has the option of hay cubing. The latter is a new practice with advantages over baling hay, primarily the opportunity of removing the crop sooner with less risk of rain damage. Cubed hay is also easier to transport and handle in automatic feeding systems with less waste (3). Artificial drying can also be utilized to allow earlier hay baling (67).

Harvesting corn as soon as it becomes physiologically mature has become a standing recommendation for making corn silage (36). A more recently developed practice is to harvest at this early date and ensile high-moisture shelled corn or high-moisture ground ear corn (38). Artificial drying would make it possible to combine the corn and store the shelled grain conventionally. The green stover, legume and grass portions removed could be made into silage.

With the various harvest and use alternatives, it is probable that harvesting activities of some type will be going on continuously on a crop somewhere during the irrigation farming season. Staggering the crop harvest dates will help program crop removal so that contractors can more efficiently schedule harvesting activities. Some staggering of planting dates each year would also be desirable.

Pest control treatments will be expected to be needed. Whenever alfalfa is present it will likely be necessary to spray for alfalfa weevil. Corn rootworm is also likely to be a problem that requires treatment at time of planting where "no-tillage" corn is involved. Other pest problems will likely occur and require attention on a demand basis. The pesticides will be applied by contracted applicators, using aerial application whenever possible. Ground application would take too long and cause delays in irrigation schedules.

IRRIGATION MANAGEMENT

Details and discussion of the quantity and rate of wastewater application is presented elsewhere in this report. The average of two inches per week for 35 weeks is planned. As much as three inches per week can be applied if necessary.

The peak water use by crops is expected to be 0.3 inches per day (45) which would be 2.1 inches per week. Rainfall averages about 0.7 inches per week during the warmer months in the southeastern Michigan area (81). With the capability of applying three inches wastewater per week, the water requirement for the crops should be met without difficulty.

The length of the irrigation season is expected to average approximately eight months. Climatic year-to-year variations could easily alter this irrigation period a month or longer (22,81). The months of April through November would be the expected irrigation period but the crop growing period would be approximately two months shorter running from about late April or May into October. The growing season varies from about 150 to 180 days in the southeastern Michigan area.

AUTOMATION AND OTHER POSSIBLE INNOVATIONS

Minimum tillage practices are intended to be used whenever possible. Tillage operations can often be combined to eliminate a separate trip through the field.

Irrigation operation offers many opportunities to use automation. Automatic valve controls and other such details are covered elsewhere in this report.

Recent developments show promise for automating graded border irrigation with labor-saving advantages similar to the benefits of automated sprinkler irrigation (27,28,41). With no complex above-ground moving equipment, minimal operating and maintenance labor is required for automated border irrigation with the return water system.

Waste heat from power generation stations possibly could be used to lenghten the crop growing season if costs were not prohibitive. Oregon State University is doing research on utilizing waste heat from electrical generating facilities and industrial plants to warm agricultural soils for crop production (5,42). Boersma _et al_. (6) reported that soil warming tests in the Williamette Valley with several crops, resulted generally in earlier maturity and yield increases from 30 to 40 percent for most crops. It was proposed that soil warming could be accomplished by circulating discharged, heated cooling water through an underground network of pipes. They calcualted that over 3000 acres of land could be warmed by using only five percent of the waste heat generated by a 1000 megawatt power generating station.

Kendrick and Havens (44) developed mathematical models to determine the heat budget of an underground piping system carrying the cooling water from steam

generation, electric power plant condensers. Depending on several variables, they indicated a range of around 12,000 to 35,000 acres could be warmed with the waste heat from one 1000 megawatt nuclear power plant.

The use of stored wastewater for irrigation without artificial heating, is not expected to accomplish a significant increase in the length of the crop growing season or irrigation season. The wastewater taken from a storage lagoon and applied as irrigation water is not expected to contribute any more thermal addition than would be expected with the use of conventional irrigation water taken from the same size irrigation reservoir. A study in Oregon indicated that even water as warm as 104°F, sprayed from a height of 8 or 10 feet, will cool to ambient air temperature by the time it reaches the ground (5).

Nitrates in the tile drainage water could be reduced by preventing the conversion of ammonia nitrogen to nitrate nitrogen by using a very selective bacteriacide, N-SERVE® nitrogen stabilizer, as a water or soil treatment (20,43,55). The ammonia form of nitrogen is adsorbed and held by soil clay particles for utilization by plants. In the absence of this chemical, bacteria may readily convert NH_4 to NO_3 which is not adsorbed by soil and readily leaches out with the drainage water. The use of N-SERVE at the beginning of the growing season would provide the basis for more efficient crop uptake of N during the rapid, summer growth period. N-SERVE biodegrades rapidly enough that its effects would have diminished

sufficiently to permit denitrification losses of N to occur from late summer to the time it might be re-applied the following spring.

Another innovation to remove NO_3 from drainage water is under study in the western U.S. (10,46,79). The technique is referred to as "submersed tile flow" and merely involves raising the tile outlet sufficiently to keep the drain tile innudated. This results in an anaerobic condition encouraging denitrification, whereupon nitrogen is converted to a gas and lost to the atmosphere. Nitrate-nitrogen losses greater than 90 percent have been attributed to the denitrification process (10,52). One requirement is that an energy source be available to the denitrifying bacteria. Organic compounds that may be present in the drainage water could possibly provide the energy source. Work by Meek et al. (53) indicated that soluble organic matter from crops would provide the energy source, moving downward with the soil solution. They attributed large losses of nitrate-nitrogen to denitrification which was very rapid in the vicinity of and below the water table (submerged zone). Nitrogen losses in the range of 20 to 76 percent have been reported without the use of the submerged tile technique (46,56,60).

If submersed tile flow were used to solve the nitrate problem there might be a problem eventually with anaerobic "clogging" of the drain system (82). This could probably be resolved by installing a valve (remotely controlled) at a low drain point at the tile outlet. Opening the valve for a temporary period would aerate the tile lines and clear the "clogging" problem.

Deep ponding is another possible method of disposing of excess nitrogen through denitrification (12,13,14,79). Evidence has been obtained indicating that the denitrification pathway of the bottom of lakes and ponds is the same as that reported for submerged soils.

Still another approach to the nitrate problem in drainage water is the use of an "algal stripping" system (9,79). Drainage water is impounded in "rapid growth ponds" where algae assimilate nitrogen and are then removed by filtration. Total nitrogen removal ranged from 70-85 percent in pilot studies. Boersma _et al_. (6) indicates that algae may remove 90 percent of the nitrogen and 50 percent of the phosphates from water.

SECTION VIII
PERFORMANCE OF LAND TREATMENT ALTERNATIVE

The CRREL study team (82) estimated performance for land treatment of wastewater. Estimates were made for three irrigation methods: spray irrigation, overland runoff, and rapid infiltration. Their estimates assumed (i) an active plant system at the soil surface, (ii) an active microbial population, (iii) a soil matrix which includes clay minerals and organic fractions, and (iv) wastewater application and climatic constraints. For the spray irrigation method, their estimated removal percentages are summarized below for major wastewater constituents.

Constituents	Percent Removal
BOD	98+
COD	95+
N	85+
P	99+
Metals	95+
Suspended solids	99
Pathogens	99

Land treatment of the Southeastern Michigan wastewater is expected to provide renovation at least equivalent to the above. This expectation is based upon (i) the medium to fine textured soils found within the Southeastern Michigan irrigation sites, (ii) abundant plant growth anticipated on the irrigation sites, (iii) irrigation systems requiring wastewater to percolate through at least five feet of aerobic soils before

reaching the underdrains, and (iv) application of two inches of wastewater per week for 35 weeks.

The Fulton-Williams site in Ohio utilizes the graded border method of irrigation. This method resembles overland runoff irrigation as described in the CRREL Report (82) in that water must travel over soil surfaces to irrigate areas further down slopes. However, the graded border method, as designed, uses underdrains and requires the wastewater to percolate downward through the soil profile before leaving the irrigation site. In this respect, the graded method produces vertical flow paths and resembles spray irrigation. Hence, the graded border method is expected to give performance equivalent to spray irrigation.

CORPS' WATER QUALITY GOALS

The U. S. Army Corps of Engineers has established guidance on critical discharge levels for wastewater constituents. Reaching these critical levels is the goal of the CORPS. These goals are shown in Table VIII-1, along with the assumed wastewater quality before and after land treatment.

The removal percentages estimated by the CRREL study team were applied to the oxygen-demanding compounds, biostimulants, metals, and suspended solids concentrations to calculate expected concentrations after land treatment. The nonmetals of boron, chlorides, and sulfates are expected to largely pass through the soil matrix. However, some small quantities of the

Table VIII-1

Concentrations of Wastewater Constituents Before and After Land Treatment Compared to the Corps' Effluent Quality Goals (All Concentrations are mg/l Unless Otherwise Noted.)

Wastewater Constituents	Typical Concentration Before Land Treatment	Expected Concentration After Land Treatment	Goals of Corps
I. Oxygen-demanding compounds			
a. BOD	25	<0.5	<2.0
b. COD	70	<3.5	-
II. Biostimulants			
a. Nitrogen	Total N 20		-
	Organic 2.0 (as N)	<3.0	Org. + NO_3 + NO_2 <10.0
	+NH_4 9.8 (as N)		<0.1
	-NO_2 0.0 (as N)		<4.0
	-NO_3 8.2 (as N)		
b. Phosphorus	Total P 10	<0.1	<0.05 <0.10
III. Other organic compounds			
a. Phenols	0.3	?	Absent
b. Chlorinated and other complex organics	Concentrations vary	?	Absent
IV. Inorganic Compounds			
a. Metals			
Cadmium	0.1	<5 ppb	Absent
Chromium	0.2	<10 ppb	Absent
Copper	0.1	<5 ppb	Absent
Iron	0.1	<5 ppb	-
Lead	0.1	<5 ppb	Absent
Manganese	0.2	<10 ppb	<0.5
Mercury	5 ppb	<0.25 ppb	Absent
Nickel	0.2	<10 ppb	Absent
Zinc	0.2	<10 ppb	Absent
Sodium	S.A.R. = 4.6	S.A.R. = 4.6	Na <10 Mg <125 Co <30
b. Non metals			
Boron	0.7	0.5	Absent
Chlorides	100	<100	<250
Sulfate	125	<125	<10
V. Other characteristics			
a. Suspended solids	25	0.25	Trace
b. pH	7.0	7.0	6.0-7.0

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nonmetals will be removed by the plants. Due to limited data, the concentrations are uncertain for organic compounds such as phenols and chlorinated hydrocarbons after land treatment. The CRREL study team (82) believes neutral, basic, and polar type organics of low molecular weight including many pesticides, chlorinated hydrocarbons, phenols, and others interact only weakly with soil mineral and organic matter. In the absence of specific information, the study team assumes these organics are not removed from wastewater by soil. Others indicate the phenols, for example, are adsorbed in the soil sufficiently well to undergo microbial degradation. If this is the case, little or no phenols would be expected in the renovated wastewater. However, chlorination of the wastewater prior to land application may produce chlorinated phenols, which may alter the rate of microbial degradation. Conceivably, certain chlorinated phenols could still be adsorbed within the soil and not be discharged into the groundwater or soil percolate. For the most part, soil chemical processes are active in retaining many types of organic compounds which are subject to biological decomposition in soils (82).

Land treatment meet the goals of the CORPS for BOD, nitrogen (assuming nitrification), phosphorus, chlorides, manganese, and suspended solids removal (Table IX-1). But, land treatment clearly fails to meet CORPS goals for boron and sulfate removal and possibly fails to meet the goals for certain organic compounds, sodium, and heavy metals removal. The CORPS goal is for heavy metals to be absent in the renovated wastewater. Absent means not detectable by standard

methods and current technology. Modern analytical instrumentation can detect heavy metals with concentrations <5-10 ppb. These are expected heavy metal concentrations after land treatment as shown in Table VIII-1.

MICHIGAN WATER QUALITY STANDARDS

The State of Michigan has generalized water quality standards for several water uses. These standards are contained in Appendix . However, detailed standards for effluent discharge depend on several factors such as stream flow rates, intended use of the stream, other effluent discharges into the stream, etc. Thus, standards for effluent discharge varies from location to location. Effluent standards[1] have been established for seven sewage treatment plants within Southeastern Michigan. These plants are either operating, undergoing construction, or planned. The most stringent standards for these plants are as listed below.

Constituent	Concentration, mg/l
BOD	4
NH_3-N	0.5
Phosphorus	1.2
Phenol	0.0138
Suspended Solids	15
Copper	0.01
Cadmium	0.02
Nickel	0.2
Zinc	0.04
Chromium	0.02
Coliforms	1000/100 ml

[1] Communication from Richard Lord, Stanley Consultants, Inc. to the Department of the Army.

Land treatment will exceed the above State standards with the possible exception of phenol. Land treatment likely fails to renovate the wastewater adequately to meet domestic water supply standards because of total dissolved solids and chlorides restraints for the Great Lakes and connecting waters. The maximum total dissolved solids shall not exceed 200 mg/1. For chlorides, the monthly average shall not exceed 50 mg/1.

SECTION IX
SUMMARY AND RECOMMENDATIONS

Land treatment shows promise for renovating wastewater for stream and groundwater recharge, industrial uses, etc. Hence, land treatment is one of several alternatives considered for the Southeastern Michigan Wastewater Management Program.

Five potential land treatment sites were selected in Southeastern Michigan and Northwestern Ohio. These sites have a total area of about 1100 square miles. Acquisition costs range from about $750 to $1375 per acre. Acquisition costs include market value of property, family relocation allowances, and other costs. Most soils found within the sites are medium textured, poorly drained under natural conditions, and on less than 6% slopes.

Portions of two potential land treatment sites were used to develop design alternates for wastewater application rates, irrigation methods, underdrain systems, erosion and runoff control, and site-related facilities such as water transmission within the site, pump stations, reuse ponds, outfalls, etc. Modular designs covering four square miles of land were developed for irrigation methods and underdrain systems. Capital cost for the center pivot irrigation module giving 95% land coverage is about $1.46 million. This design was selected for use on the four irrigation sites within

Michigan. Capital cost for the graded border irrigation module is about $2.15 million. The graded border irrigation method was selected for the Fulton-Williams site in Ohio. The modular design selected for the underdrain system has tile laterals spaced on 33 foot centers and requires about $1.7 million capital expenditure. Wastewater application rate will average two inches per week for 35 weeks (70 inches/year). This rate was selected based on soil characteristics, crops to be grown, wastewater constituents, and desired wastewater renovation. Wastewater will flow through the irrigation site to the irrigation modules in clay-lined open channels. Renovated water flows from the underdrain modules in an unlined open channel and is pumped into reuse ponds. From the reuse ponds, the renovated wastewater is discharged into nearby streams for augmentation.

The selected cropping system is a 10 or 12 year rotation of alfalfa-smooth bromegrass, alfalfa-bromegrass-corn, alfalfa-bromegrass-red clover, and reed canarygrass. The recommended harvest method is field chopping. A harvest method requiring the crop to go beyond maturity to field dried conditions is least desirable. Such practice would significantly interrupt the irrigation schedule.

The five irrigation sites can treat about 1.23×10^{12} gallons of wastewater during the planned 35 week irrigation season. On an annual basis, this is equivalent to about 3366 MGD. The four sites located in Michigan can treat the equivalent of 2796 MGD. For all five sites, the capital, O&M, and annualized

costs average about $1367, $57, and $137 per million gallons of treated wastewater, respectively. These costs do not include raw sewage collection and transmission, lagoon treatment and storage, disinfection, and sludge disposal.

Land treatment is expected to remove 98% of the BOD, 95% COD, 85% N, 99% P, 95% metals, 99% suspended solids, and 99% of the pathogens contained in the Southeastern Michigan wastewater. This expected performance is based on estimates made by the CRREL study team (82).

For the Southeastern Michigan Wastewater Management Program, land treatment is a workable system for wastewater renovation. Other alternatives such as advanced biological and physical-chemical treatment of wastewater may also be workable systems. Hence, the alternative selected for Southeastern Michigan should offer optimum cost-performance relationships and should have acceptable social, environmental, and institutional impacts. The best alternative can only be selected after all studies currently being sponsored by the CORPS are completed.

If land treatment is selected for the Southeastern Michigan Wastewater Management Program, a "pilot study" is recommended before detailed design of the irrigation sites is commenced. This pilot study should encompass at least a module size area (four square miles). This study is needed to verify under typical field conditions, such parameters as wastewater application rates, tile

lateral spacings and depths, quantity and quality of renovated water, evapotranspiration rates, farm operation procedures, suitability of irrigation equipment, labor requirements, crops systems and yields, etc. The pilot study should be conducted under close and capable supervision for a few years prior to starting detailed design. After this, the pilot study should continue for a few years while the irrigation sites are undergoing detailed design. The module used for the pilot study should be within one of the irrigation sites and should become a working module when the irrigation site becomes operational. Data from other operational land treatment facilities (such as Muskegon) in Michigan will be helpful, but probably inadequate due mainly to soil differences and anticipated cropping and management differences.

SECTION X

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APPENDICES

APPENDIX A

Designs and Costs for Phase I - Sites Used as a Basis for Selection of Design Alternatives

Appendix A-1 - Monroe and St. Clair Phase I Sites

Appendix A-2 - Alternate Size for Monroe Phase I Site

Appendix A-3 - Transmission of Water to Irrigation Modules, Monroe Phase I Site, Village of Ida Deleted from Site

Appendix A-4 - Transmission of Water to Irrigation Modules, Monroe Phase I Site, Village of Ida Included in Site

Appendix A-5 - Collection and Discharge of Water from Drainage Modules, Monroe Phase I Site, Village of Ida Deleted from Site

Appendix A-6 - Collection and Discharge of Water from Drainage Modules, Monroe Phase I Site, Village of Ida Included in Site

Appendix A-7 - Transmission of Water to Irrigation Modules, St. Clair - Phase I Site

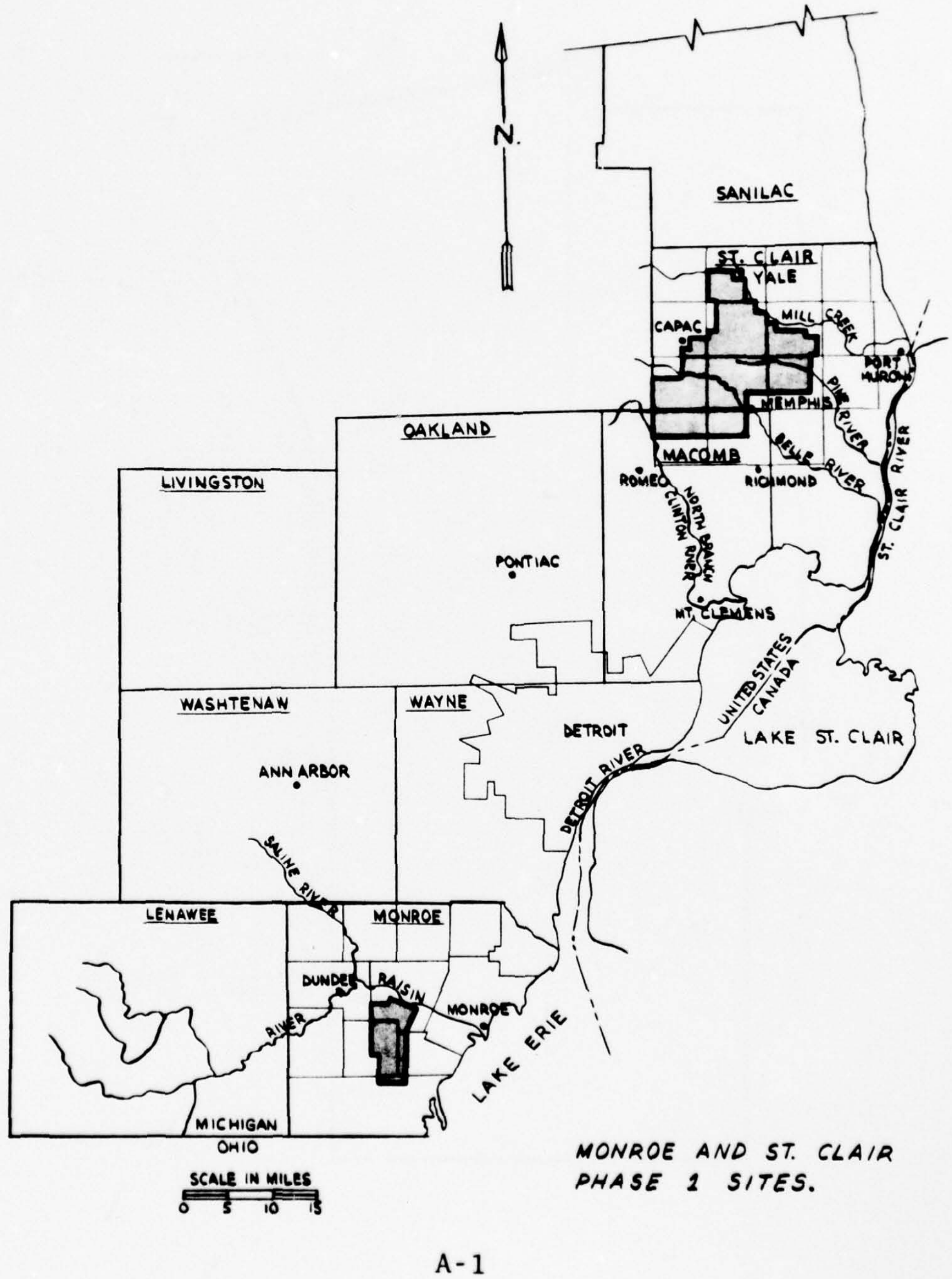
Appendix A-8 - Collection and Discharge of Water from Drainage Modules, St. Clair - Phase I Site

Appendix A-9 - Summary of Design Alternatives for Monroe Phase I Site, Village of Ida Deleted from Site

Appendix A-10 - Summary of Design Alternatives for Monroe Phase I Site, Village of Ida Included in Site

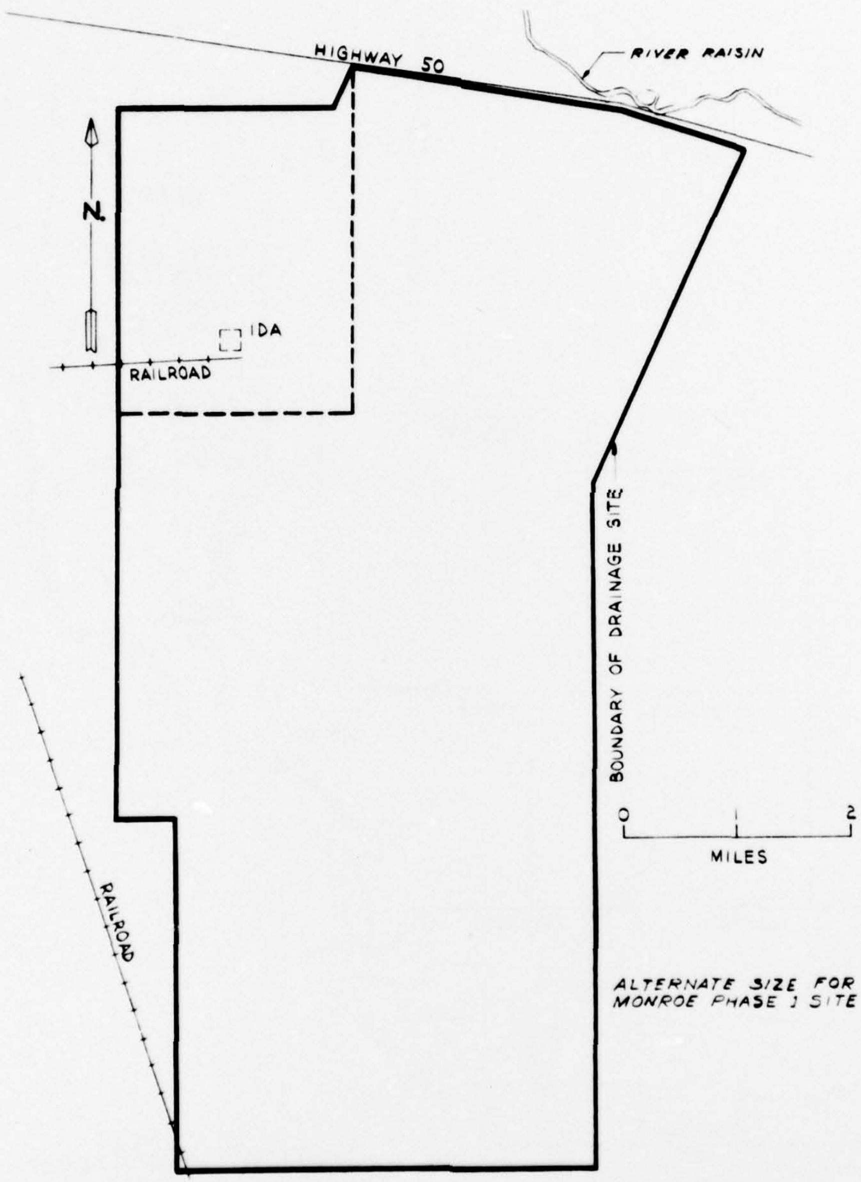
Appendix A-11 - Summary of Design Alterations for St. Clair Phase I Site

APPENDIX A-1

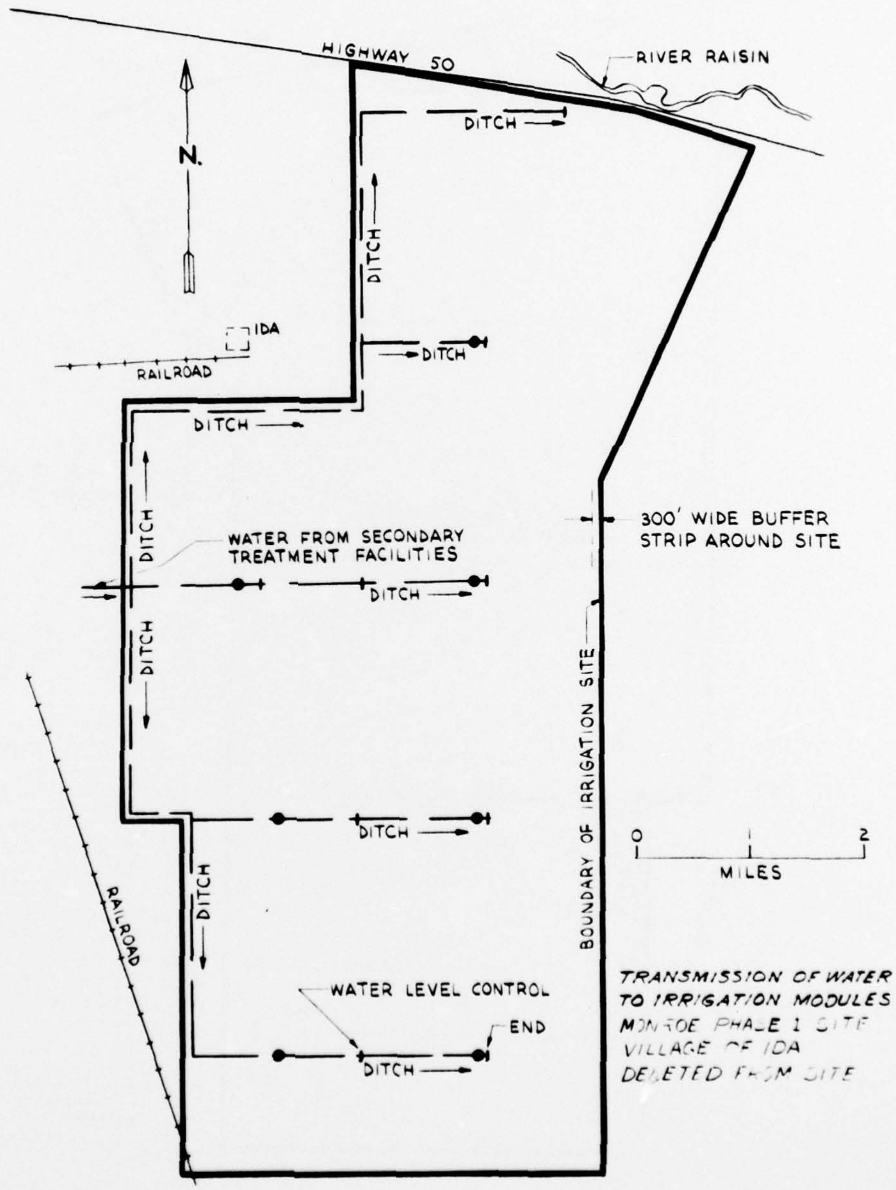


MONROE AND ST. CLAIR
PHASE 1 SITES.

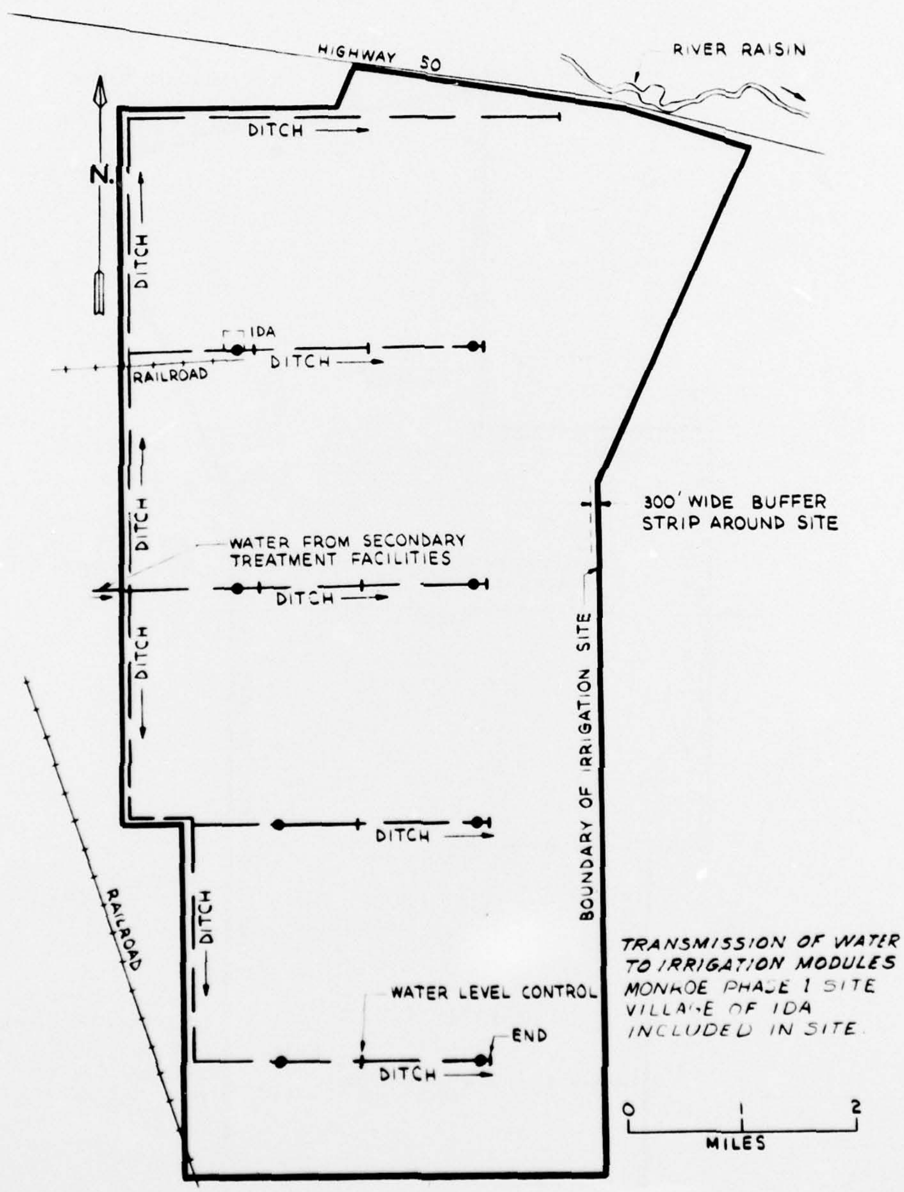
APPENDIX A-2


HIGHWAY 50
RIVER RAISIN
N
IDA
RAILROAD
BOUNDARY OF DRAINAGE SITE
0
2
MILES
RAILROAD
ALTERNATE SIZE FOR
MONROE PHASE 1 SITE

APPENDIX A-3

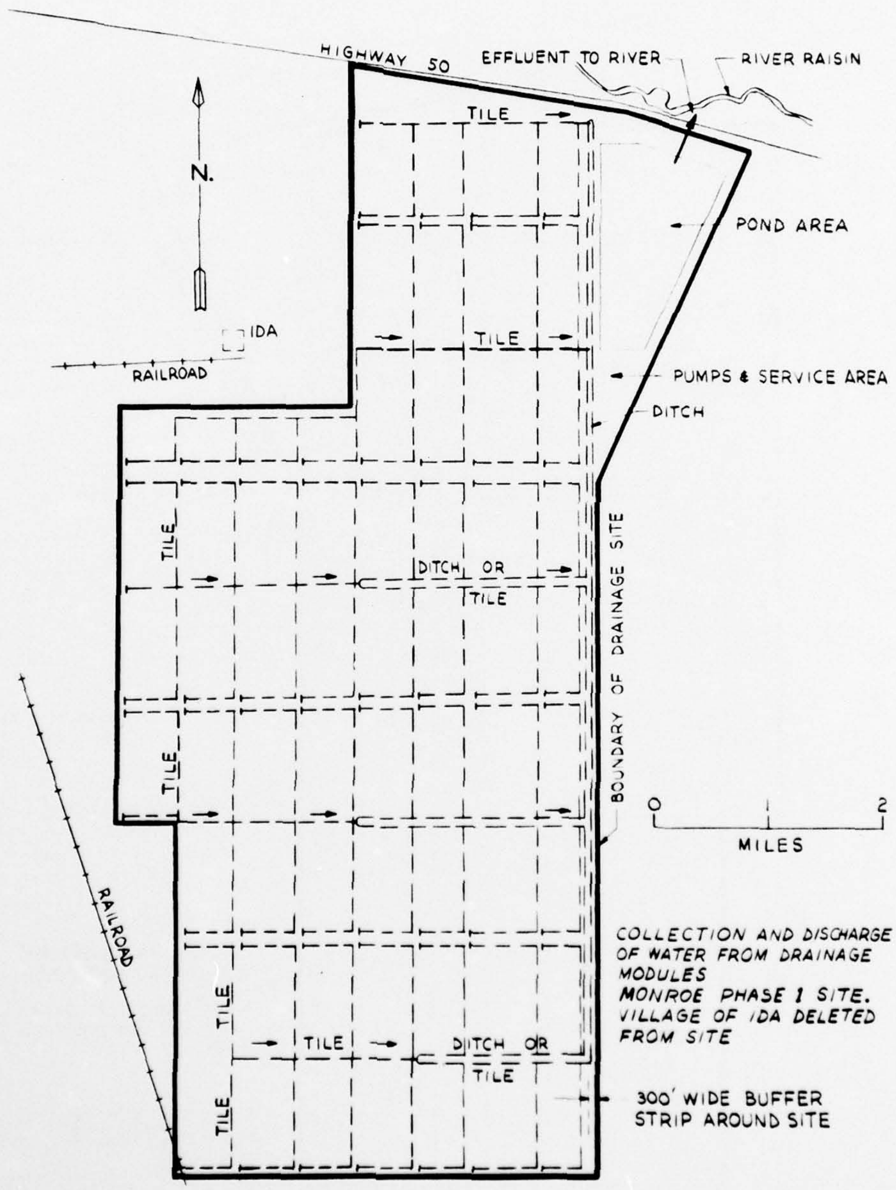

HIGHWAY 50
RIVER RAISIN
N.
DITCH
IDA
RAILROAD
300' WIDE BUFFER
STRIP AROUND SITE
WATER FROM SECONDARY
TREATMENT FACILITIES
BOUNDARY OF IRRIGATION SITE
0
1
2
MILES
WATER LEVEL CONTROL
END
TRANSMISSION OF WATER
TO IRRIGATION MODULES
MONROE PHASE 1 SITE
VILLAGE OF IDA
DELETED FROM SITE

APPENDIX A-4

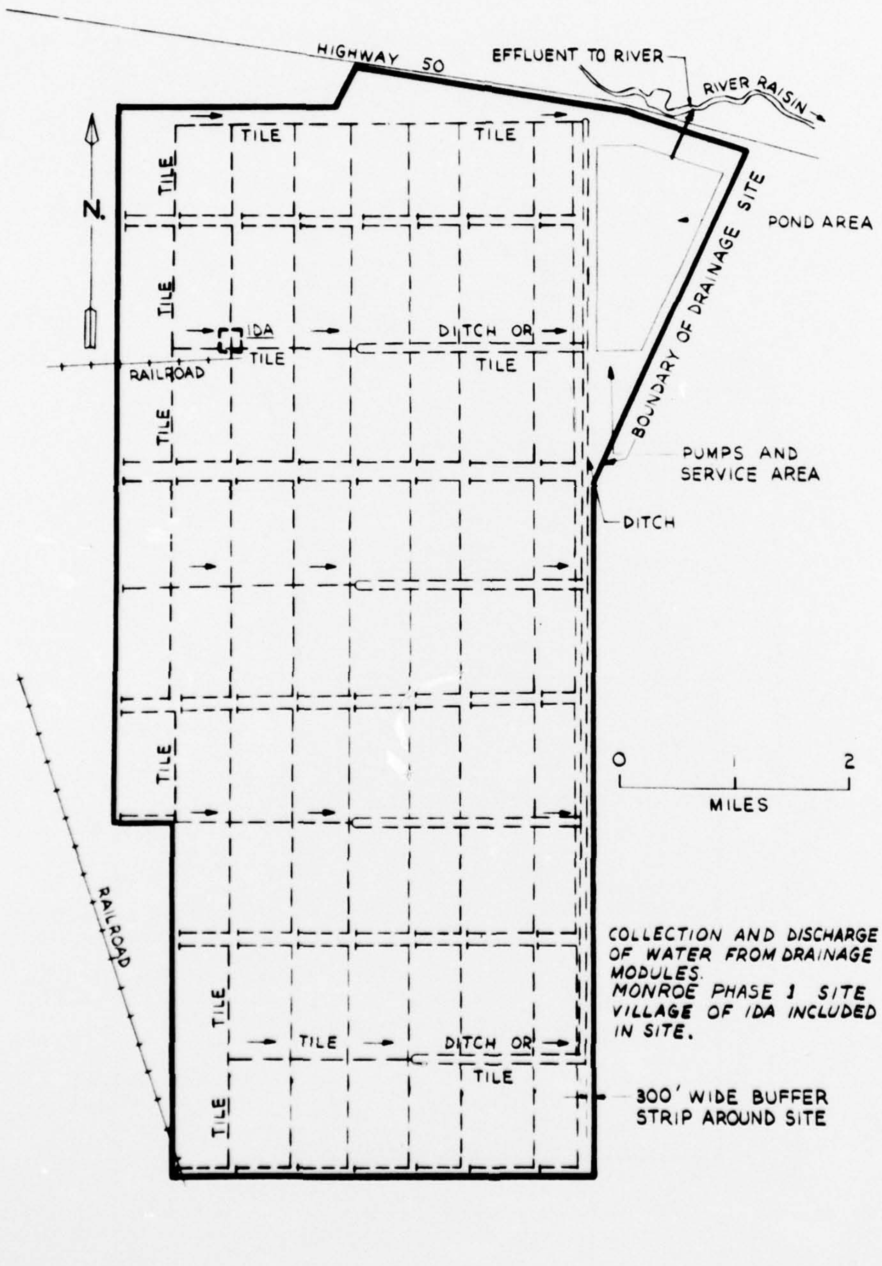


TRANSMISSION OF WATER TO IRRIGATION MODULES
MONROE PHASE 1 SITE
VILLAGE OF IDA
INCLUDED IN SITE

APPENDIX A-5

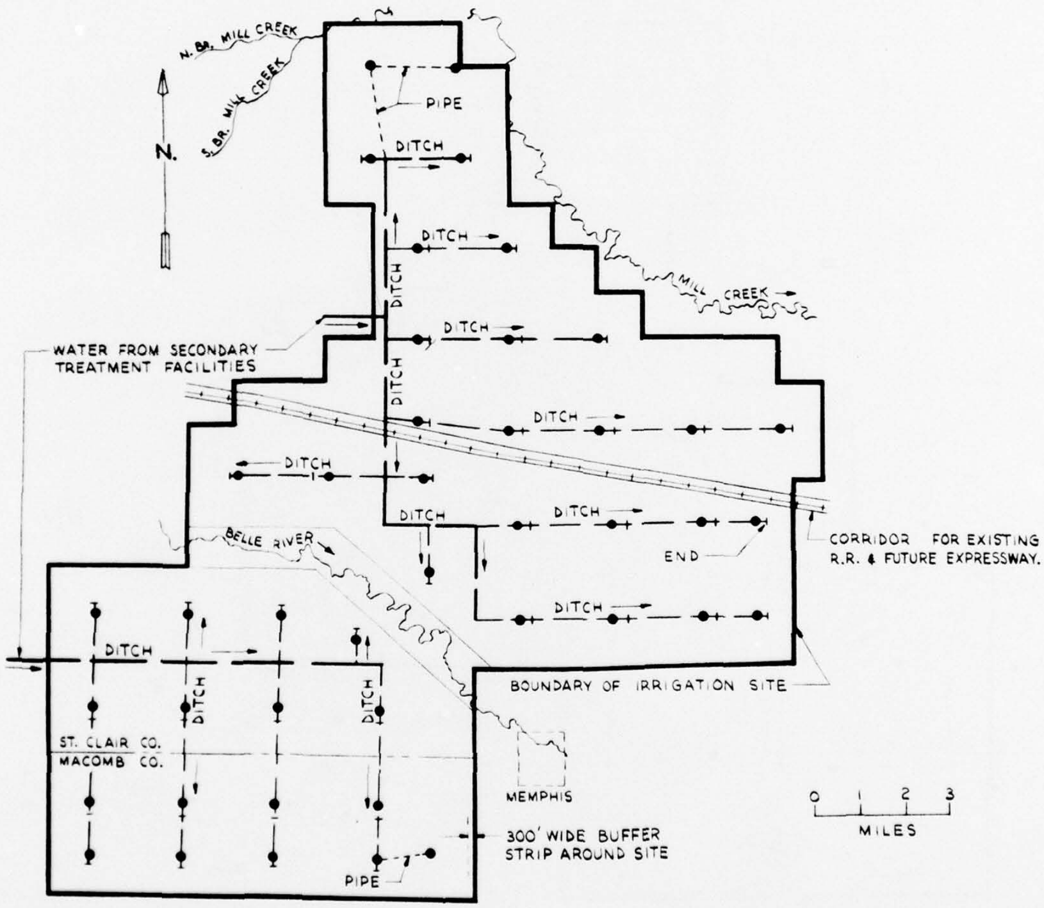

HIGHWAY 50
EFFLUENT TO RIVER
RIVER RAISIN
N.
TILE
POND AREA
IDA
RAILROAD
TILE
PUMPS & SERVICE AREA
DITCH
TILE
DITCH OR TILE
BOUNDARY OF DRAINAGE SITE
TILE
0 1 2
MILES
RAILROAD
COLLECTION AND DISCHARGE OF WATER FROM DRAINAGE MODULES
MONROE PHASE 1 SITE.
VILLAGE OF IDA DELETED FROM SITE
TILE
TILE
DITCH OR TILE
TILE
300' WIDE BUFFER STRIP AROUND SITE

APPENDIX A-6



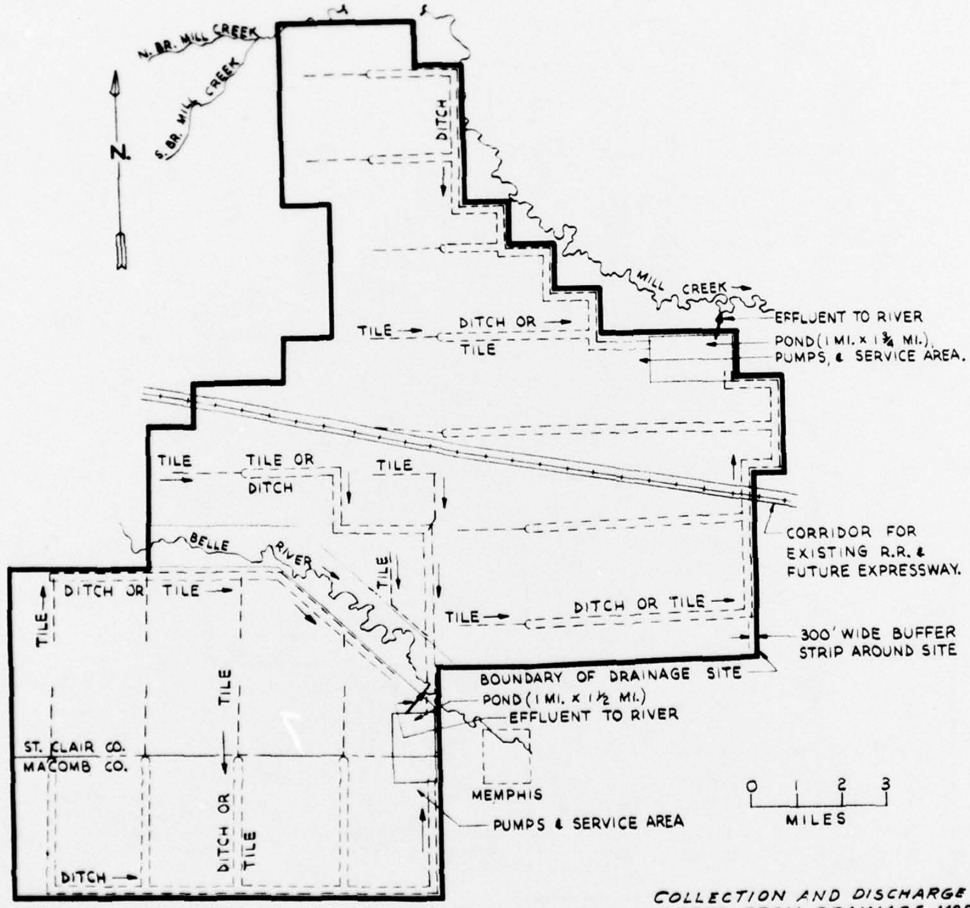
HIGHWAY 50
EFFLUENT TO RIVER
RIVER RAISIN
TILE
TILE
TILE
N.
TILE
POND AREA
BOUNDARY OF DRAINAGE SITE
TILE
IDA
DITCH OR
TILE
TILE
RAILROAD
TILE
PUMPS AND
SERVICE AREA
DITCH
0
2
MILES
TILE
RAILROAD
COLLECTION AND DISCHARGE OF WATER FROM DRAINAGE MODULES.
MONROE PHASE 1 SITE
VILLAGE OF IDA INCLUDED IN SITE.
TILE
TILE
DITCH OR
TILE
300' WIDE BUFFER STRIP AROUND SITE
TILE

APPENDIX A-7



TRANSMISSION OF WATER TO IRRIGATION MODULES ST. CLAIR — PHASE 1 SITE.

APPENDIX A-8



COLLECTION AND DISCHARGE OF WATER FROM DRAINAGE MODULES ST. CLAIR — PHASE 1 SITE

APPENDIX A-9

	SUMMARY FOR MONROE COUNTY — PHASE 1 SITE WITH VILLAGE OF IDA EXCLUDED FROM SITE	UNITS	UNIT $ COST	CAPITAL $ COST	O.&M. $ COST	ENERGY REQ'D. (KWH/Y)	LAND USED (ACRES)	ANNUAL WASTEWATER APPLICATION (MG)	DESIGN INFLOW (MGD)
SITE	LAND								
	ACQUISITION	~21,900 AC.	985	21,561,000					
	FAMILY RELOCATION	~ 694 FAM.	5,000	3,468,000					
	LEGAL ADMIN., ETC.	PLUS	10%	2,503,000					
	WOODLAND CLEARING	1360	380	516,800					
	SITE PREPARATION	21,900	70	1,533,000					
	IRRIGATION AREA								
	CENTER PIVOT RIG 76%						15,600	29,600	81
	CENTER PIVOT RIG 91%						8,600	35,300	96
	CENTER PIVOT RIG 95%						19,500	37,000	101
	FIXED SET SPRAY						19,900	37,800	103
	GRADED BORDER						19,500	37,000	101
	FURROW						19,500	37,000	101
DISINFECTION	CHLORINATION	1 EACH	44,000	44,000	128,100				
TRANSMISSION	CLAY LINED CHANNEL	21.8 MI.	43,420	946,500	9,460				
	PVC LINED CHANNEL	21.8 MI.	70,760	1,542,600	15,400				
	CONCRETE LINED CHANNEL	21.8 MI.	179,175	3,906,000	20,000				
	UNDERGROUND PIPE	21.8 MI.	239,870	5,163,800	26,000				
	PUMPING			NOTE 1					
IRRIGATION METHOD	CENTER PIVOT RIG — 76%	8.0 MOD.	1,408,800	11,270,400	1,093,000 *	29,568,000			
	CENTER PIVOT RIG — 91%	8.0 "	2,003,600	16,028,800	1,435,000 *	40,320,000			
	CENTER PIVOT RIG — 95%	8.0 "	1,461,000	11,688,000	1,233,000 *	39,200,000			
	RUNOFF CONTROL	8.0 "							
	WITH LAND CELLS	8.0 "	76,800	614,400	101,600				
	WITHOUT LAND CELLS	8.0 "	38,400	307,200	70,400				
	FIXED SET SPRAY	8.0 "	10,811,700	86,493,600	2,240,000 *	55,200,000			
	RUNOFF CONTROL	8.0 "	38,400	307,200	70,400				
	GRADED BORDER	8.0 "	2,115,000	16,920,000	1,079,000 *				
	FURROW	8.0 "	2,127,500	17,020,000	1,102,000 *				
DRAINAGE	33 FT. LATERALS	8.0 "	1,675,600	13,404,800	398,400	7,424,000			
	55 FT. LATERALS	8.0 "	1,329,700	10,637,600	343,200	7,424,000			
	16.5 FT. LAT'S. WITH ASPHALT BARRIER	8.0 MOD.	6,905,500	55,244,000	1,235,200	7,424,000			
REUSE	TRANSMISSION TO STORAGE FACILITY								
	CHANNEL	14 MI.		234,800	2,350				
	CLAY LINED CHANNEL	14 MI.		626,000	6,260				
	PIPE	14 MI.		3,696,000	18,500				
	PUMPING	4350 H.P.	80	350,000	327,500	25,578,000			
	STORAGE FACILITY	1,100,000 CY.	.170	1,863,000	18,630				
	RETURN TO TREATMENT AND STORAGE LAGOONS								
	PUMP	6000 H.P.	80	480,000	49,500	3,240,000			
	PIPELINE	7.5 MI.	450,000	3,375,000	16,875				
OUTFALLS	TRANSMISSION								
	CHANNEL	0.3 MI.	40,000	12,000	120				
	CLAY LINED CHANNEL	0.3 MI.	75,000	22,500	225				
	CONCRETE LINED CHANNEL	0.3 MI.	260,000	78,000	780				
	PIPE	0.3 MI.	845,000	253,500	1,260				
	STREAM OUTFALLS	ONE	20,000	20,000	200				
GROUNDWATER CONTROL	DITCH AROUND SITE	28 MI.	31,700	887,000	8,870				
	OBSERVATION WELLS	5,800 L.F.	8.00	46,400	500				
	UPLAND DITCH AROUND SITE	11 MI.	15,000	165,000	1650				
GENERAL SITE	ELECTRICAL	8.0 MOD.	100,000	800,000	23,200				
	ADMINISTRATIVE & LABORATORY	1 EACH	260,500	260,500	154,000				
	SITE MAINTENANCE	1 EACH	88,000	88,000	136,600				

1. PUMPING COST INTO SITE DEPENDS UPON LOCATION AND DESIGN OF TREATMENT STORAGE LAGOON.

* REVISED

SUMMARY OF DESIGN ALTERNATIVES FOR MONROE PHASE 1 SITE, VILLAGE OF IDA DELETED FROM SITE.

APPENDIX A-10

		UNITS	UNIT $ COST	CAPITAL $ COST	O.& M. $ COST	ENERGY REQ'D. (KWH/Y)	LAND USED (ACRES)	ANNUAL WASTEWATER APPLICATION (MG)	DESIGN INFLOW (MGD)
SUMMARY FOR MONROE COUNTY — PHASE 1 SITE WITH VILLAGE OF IDA INCLUDED IN SITE									
SITE	LAND								
	ACQUISITION	~25,250 AC.	1217	30,724,000					
	FAMILY RELOCATION	~1,320 FAM.	5,000	6,602,000					
	LEGAL ADMIN., ETC.	PLUS	0%	3,733,000					
	WOODLAND CLEARING	1560 AC.	380	592,800					
	SITE PREPARATION	25,250 AC.	100	2,525,000					
	IRRIGATION AREA								
	CENTER PIVOT RIG – 76%						16,900	34,400	94
	CENTER PIVOT RIG – 91%						21,700	41,200	112
	CENTER PIVOT RIG – 95%						22,600	43,000	117
	FIXED SET SPRAY						23,100	43,900	120
	GRADED BORDER						22,600	43,000	117
	FURROW						22,600	43,000	117
DISINFECTION	CHLORINATION	1 EACH	52,500	52,500	49,400				
TRANSMISSION	CLAY LINED CHANNEL	22.8 MI.	42,380	966,300	9600				
	PVC LINED CHANNEL	22.8 MI.	68,130	1,553,400	15,500				
	CONCRETE LINED CHANNEL	22.8 MI.	185,175	4,222,000	21,100				
	UNDERGROUND PIPE	22.8 MI.	246,166	5,612,600	28,000				
	PUMPING			NOTE 1.					
IRRIGATION METHOD	CENTER PIVOT RIG – 76%	9.3 MOD.	1,408,800	13,101,800	1,270,000 *	34,372,800			
	CENTER PIVOT RIG – 91%	9.3 "	2,003,600	18,633,500	1,666,000 *	46,872,000			
	CENTER PIVOT RIG – 95%	9.3 "	1,461,000	13,587,300	1,433,000 *	45,570,000			
	RUNOFF CONTROL	9.3 "							
	WITH LAND CELLS	9.3 "	76,800	714,200	118,100				
	WITHOUT LAND CELLS	9.3 "	38,400	357,100	81,800				
	FIXED SET SPRAY	9.3 "	10,811,700	100,548,800	2,600,000 *	64,110,000			
	RUNOFF CONTROL	9.3 "	38,400	357,100	81,800				
	GRADED BORDER	9.3 "	2,115,000	19,669,500	1,225,000 *				
	FURROW	9.3 "	2,127,500	19,785,800	1,281,000 *				
DRAINAGE	33 FT. LATERALS	9.3 "	1,675,600	15,583,100	463,100	8,630,400			
	55 FT. LATERALS	9.3 "	1,329,700	12,366,200	399,000	8,630,400			
	16.5 FT. LATS. WITH ASPHALT BARRIER	9.3 MOD.	6,905,500	64,221,200	1,435,900	8,630,400			
REUSE	TRANSMISSION TO STORAGE FACILITY								
	CHANNEL	16 MI.	16,560	265,000	2,650				
	CLAY LINED CHANNEL	16 MI.	44,375	710,000	7,100				
	PIPE	16 MI.	257,400	4,118,400	20,600				
	PUMPING	4,350 H.P.	80	350,000	327,500	25,578,000			
	STORAGE FACILITY	1,100,000 CY.	1.70	1,863,000	18,630				
	RETURN TO TREATMENT AND STORAGE LAGOONS								
	PUMP	6,000 H.P.	80	480,000	49,500	3,240,000			
	PIPELINE	7.5 MI.	450,000	3,375,000	16,875				
OUTFALLS	TRANSMISSION								
	CHANNEL	0.3 MI.	40,000	12,000	120				
	CLAY LINED CHANNEL	0.3 MI.	75,000	22,500	225				
	CONCRETE LINED CHANNEL	0.3 MI.	260,000	78,000	780				
	PIPE	0.3 MI.	845,000	253,500	1260				
	STREAM OUTFALLS	ONE	20,000	20,000	200				
GROUNDWATER CONTROL	DITCH AROUND SITE	28 MI.	31,700	887,000	.8870				
	OBSERVATION WELLS	5,800 L.F.	8.00	46,400	500				
	UPLAND DITCH AROUND SITE	11 MI.	15,000	165,000	1650				
GENERAL SITE	ELECTRICAL	9.3 MOD.	100,000	930,000	27,300				
	ADMINISTRATIVE & LABORATORY	1 EACH	296,000	296,000	175,000				
	SITE MAINTENANCE	1 EACH	100,000	100,000	155,200				

1. PUMPING COST INTO SITE DEPENDS UPON LOCATION AND DESIGN OF TREATMENT STORAGE LAGOON.

* REVISED

SUMMARY OF DESIGN ALTERNATIVES FOR MONROE — PHASE 1 SITE. VILLAGE OF IDA INCLUDED IN SITE.

APPENDIX A-11

SUMMARY FOR ST. CLAIR COUNTY— PHASE 1 SITE

		UNITS	UNIT $ COST	CAPITAL $ COST	O.& M. $ COST	ENERGY REQ'D. (KWH/Y)	LAND USED (ACRES)	ANNUAL WASTEWATER APPLICATION (MG)	DESIGN INFLOW (MGD)
SITE	LAND								
	ACQUISITION	~109,700 AC.	694	76,14,000					
	FAMILY RELOCATION	~1863 FAM.	5,000	9,315,000					
	LEGAL ADMIN. ETC.	PLUS	10%	8,543,000					
	WOODLAND CLEARING	13,600 AC.	380	5,168,000					
	SITE PREPARATION	109,700 AC	45	4,936,500					
	IRRIGATION AREA								
	CENTER PIVOT RIG – 76%						75,700	143,900	394
	CENTER PIVOT RIG – 91%						90,600	172,100	471
	CENTER PIVOT RIG – 95%						94,600	179,700	492
	FIXED SET SPRAY						96,600	183,500	502
	GRADED BORDER						94,600	179,700	492
	FURROW						94,600	179,700	492
DISINFECTION	CHLORINATION	1 EACH	226,000	226,000	578,100				
TRANSMISSION	CLAY LINED CHANNEL	67.7 MI.	51,872	3,511,800	35,200				
	PVC LINED CHANNEL	67.7 MI.	83,563	5,657,200	56,600				
	CONCRETE LINED CHANNEL	67.7 MI.	204,300	13,832,300	69,000				
	UNDERGROUND PIPE	67.7 MI.	420,300	28,453,600	142,000				
	PUMPING			NOTE 1					
IRRIGATION METHOD	CENTER PIVOT RIG – 76%	38.9 MOD.	1,408,800	54,802,300	5,314,000*	143,774,400			
	CENTER PIVOT RIG – 91%	38.9 "	2,003,600	77,940,000	6,979,000*	196,056,000			
	CENTER PIVOT RIG – 95%	38.9 "	1,461,000	56,832,900	5,994,000*	190,610,000			
	RUNOFF CONTROL	38.9 "							
	WITH LAND CELLS	38.9 "	153,600	5,975,000	793,600				
	WITHOUT LAND CELLS	38.9 "	38,400	1,493,800	342,300				
	FIXED SET SPRAY	38.9 "	10,811,700	420,575,100	10,892,000*	268,410,000			
	RUNOFF CONTROL	38.9 "	38,400	1,493,800	342,300				
	GRADED BORDER	38.9 "	2,190,000	85,191,000	5,539,000*				
	FURROW	38.9 "	2,202,500	85,677,300	5,648,000*				
DRAINAGE	33 FT. LATERALS	38.9 "	1,675,600	65,180,800	1,937,200	36,099,200			
	55 FT. LATERALS	38.9 "	1,329,700	51,725,300	1,668,800	36,099,200			
	16.5 FT. LAT'S. WITH ASPHALT BARRIER	38.9 MOD.	6,905,500	268,624,000	6,006,200	36,099,200			
REUSE	TRANSMISSION TO STORAGE FACILITY								
	CHANNEL	73.4 MI.	17,500	1,287,700	12,900				
	CLAY LINED CHANNEL	73.4 MI.	46,400	3,408,300	34,000				
	PIPE	73.4 MI.	308,400	22,637,500	113,000				
	PUMPING	15,300 H.P.	80	1,224,000	1,155,000	90,000,000			
	STORAGE FACILITY	2,750,000CY	1.70	4,675,000	46,750				
	RETURN TO TREATMENT AND STORAGE LAGOONS								
	PUMP	17,260 H.P.	80	1,380,800	140,790	8,700,000			
	PIPELINE	18.0 MI.	450,000	8,100,000	40,000				
OUTFALLS	TRANSMISSION								
	CHANNEL	1.5 MI.	41,200	61,800	700				
	CLAY LINED CHANNEL	1.5 MI.	91,000	136,500	1400				
	CONCRETE LINE CHANNEL	1.5 MI.	305,000	457,500	4,600				
	PIPE	1.5 MI.	1,584,000	2,376,000	24,000				
	STREAM OUTFALLS	TWO	40,000	80,000	800				
GROUNDWATER CONTROL	DITCH AROUND SITE	85 MI.	31,700	2,695,000	26,950				
	OBSERVATION WELLS	14,800 L.F.	8.00	118,400	1,200				
	UPLAND DITCH AROUND SITE	(NOT NEEDED)							
GENERAL SITE	ELECTRICAL	38.9 MOD.	100,000	3,890,000	112,800				
	ADMINISTRATIVE & LABORATORY	1 EACH	888,000	888,000	525,000				
	SITE MAINTENANCE	1 EACH	300,000	300,000	465,600				

1. PUMPING COST INTO SITE DEPENDS UPON LOCATION AND DESIGN OF TREATMENT STORAGE LAGOON.

* REVISED

SUMMARY OF DESIGN ALTERATIONS FOR ST. CLAIR —— PHASE 1 SITE

APPENDIX B

SINKING FUND FACTORS

Bases: "Economic Effect" paragraph 15, Corps of Engineers Manual, EM-1120-2-104.

	Factor		
Years Replaced	5 1/2%	7%	10%
25	0.01955	0.01581	0.01017
16	.04029	.03564	.02778
10	.07767	.07238	.06275
8	.10205	.09694	.08730
5	.17918	.17389	.16380

Pumping Station Example

			5 1/2%
65% Capital not replaced			
20% Capital 25 yrs	x	0.0196	= 0.00392
5% Capital 16 yrs	x	.0402	= 0.00201
5% Capital 10 yrs	x	.0777	= 0.00388
5% Capital 8 yrs	x	.1020	= 0.00510
Factor			= 0.01491

APPENDIX C

LAND ACQUISITION COSTS
(Including River Corridors)

M $ = $1000	Huron-Tuscola	St. Clair[1]	Monroe	Lenawee	Williams/Fulton
Size, Acres	423,680	177,075	58,709	24,033	141,120
Miles	662	277	92	37.6	220
Land Acquisition, M$	281,129	108,263	63,619	23,068	95,479
$/Acre	664	611	1,084	960	677
Family Relocation, M$	28,855	12,639	9,952	2,005	18,492
Families	5,771	2,528	1,990	401	3,698
Administrative, Legal, etc. M$	30,968	12,092	7,358	2,507	11,397
TOTAL, M$	340,952	132,994	80,929	27,580	125,368
$/Acre	805	751	1,378	1,148	888

1 Excluding Detroit Edison site 6 mile^2 and sludge acreage requirements

APPENDIX D

MICHIGAN WATER QUALITY STANDARDS

COMMISSION OBJECTIVE:

WATERS IN WHICH THE EXISTING QUALITY IS BETTER THAN THE ESTABLISHED STANDARDS ON THE DATE WHEN SUCH STANDARDS BECOME EFFECTIVE WILL NOT BE LOWERED IN QUALITY BY ACTION OF THE WATER RESOURCES COMMISSION UNLESS AND UNTIL IT HAS BEEN AFFIRMATIVELY DEMONSTRATED TO THE MICHIGAN WATER RESOURCES COMMISSION AND THE DEPARTMENT OF THE INTERIOR THAT THE CHANGE IN QUALITY WILL NOT BECOME INJURIOUS TO THE PUBLIC HEALTH, SAFETY, OR WELFARE, OR BECOME INJURIOUS TO DOMESTIC, COMMERCIAL, INDUSTRIAL, AGRICULTURAL, RECREATIONAL OR OTHER USES WHICH ARE BEING MADE OF SUCH WATERS, OR BECOME INJURIOUS TO THE VALUE OR UTILITY OF RIPARIAN LANDS; OR BECOME INJURIOUS TO LIVESTOCK, WILD ANIMALS, BIRDS, FISH, AQUATIC LIFE OR PLANTS, OR THE GROWTH OR PROPAGATION THEREOF BE PREVENTED OR INJURIOUSLY AFFECTED; OR WHEREBY THE VALUE OF FISH AND GAME MAY BE DESTROYED OR IMPAIRED, AND THAT SUCH LOWERING IN QUALITY WILL NOT BE UNREASONABLE AND AGAINST PUBLIC INTEREST IN VIEW OF THE EXISTING CONDITIONS IN ANY INTERSTATE WATERS OF MICHIGAN.

WATER WHICH DOES NOT MEET THE STANDARDS WILL BE IMPROVED TO MEET THE STANDARDS.

PARAMETERS / WATER USES	COLIFORM GROUP (Organisms/100 ml. or MPN) 1	DISSOLVED OXYGEN (mg/l) 2	SUSPENDED, COLLOIDAL & SETTLEABLE MATERIALS 3	RESIDUES (Debris and material of unnatural origin and oils) 4	TOXIC & DELETERIOUS SUBSTANCES 5
A WATER SUPPLY (1) DOMESTIC. Such as drinking, culinary and food processing.	FOR GREAT LAKES & CONNECTING WATERS: The monthly average shall not exceed 2000 nor shall 20% of the samples examined exceed 2000. FOR INLAND WATERS: The monthly average shall not exceed 5000 nor shall 20% of the samples examined exceed 5000, nor exceed 20,000 in more than 5% of the samples.	Present at all times in sufficient quantities to prevent nuisance.	No objectionable unnatural turbidity, color, or deposits in quantities sufficient to interfere with the designated use.	Floating solids: None of unnatural origin. Residues: No evidence of such material except of natural origin. No visible film of oil, gasoline or related materials. No globules of grease.	Conform to current USPHS Drinking Water Standards except: Cyanide: Normally not detectable with a maximum upper limit of 0.2 mg/l. Chromium[6]: Normally not detectable with a maximum upper limit of 0.05 mg/l. Phenol: Limitations as defined under A-8.
(2) INDUSTRIAL. Such as cooling and manufacturing process.	The average of any series of 10 consecutive samples shall not exceed 5000 nor shall 20% of the samples examined exceed 10,000. The average fecal coliform density for the same 10 consecutive samples shall not exceed 1000.	Present at all times in sufficient quantities to prevent nuisance.	No objectionable unnatural turbidity, color, or deposits in quantities sufficient to interfere with the designated use.	Floating solids: None of unnatural origin. Residues: No evidence of such material except of natural origin. No visible film of oil, gasoline or related materials. No globules of grease.	Limited to concentrations less than those which are or may become injurious to the designated use.
B RECREATION (1) TOTAL BODY CONTACT. Such as swimming, water-skiing and skin-diving.	The average of any series of 10 consecutive samples shall not exceed 1000 nor shall 20% of the samples examined exceed 5,000. The average fecal coliform density for the same 10 consecutive samples shall not exceed 100.	Present at all times in sufficient quantities to prevent nuisance.	No objectionable unnatural turbidity, color, or deposits in quantities sufficient to interfere with the designated use.	Floating Solids: None of unnatural origin. Residues: No evidence of such material except of natural origin. No visible film of oil, gasoline or related materials. No globules of grease.	Limited to concentrations less than those which are or may become injurious to the designated use.
(2) PARTIAL BODY CONTACT. Such as fishing, hunting, trapping, and boating.	The average of any series of 10 consecutive samples shall not exceed 5000 nor shall 20% of the samples examined exceed 10,000. The average fecal coliform density for the same 10 consecutive samples shall not exceed 1000.	Present at all times in sufficient quantities to prevent nuisance.	No objectionable unnatural turbidity, color, or deposits in quantities sufficient to interfere with the designated use.	Floating solids: None of unnatural origin. Residues: No evidence of such material except of natural origin. No visible film of oil, gasoline or related materials. No globules of grease.	Limited to concentrations less than those which are or may become injurious to the designated use.
C FISH, WILDLIFE AND OTHER AQUATIC LIFE. Such as growth and propagation.	The average of any series of 10 consecutive samples shall not exceed 5000 nor shall 20% of the samples examined exceed 10,000. The average fecal coliform density for the same 10 consecutive samples shall not exceed 1000.	At the average low river flow of 7-day duration expected to occur once in 10 years the following DO values shall be maintained for: Intolerant fish - cold water species: Not less than 6 at any time. Intolerant fish - warm water species: Average daily DO not less than 5, nor shall any single value be less than 4. Tolerant fish - warm water species: Average daily DO not less than 4, nor shall any single value be less than 3. At greater flows the DO shall be in excess of these values.	No objectionable unnatural turbidity, color, or deposits in quantities sufficient to interfere with the designated use.	Floating solids: None of unnatural origin. Residues: No evidence of such material except of natural origin. No visible film of oil, gasoline or related materials. No globules of grease.	Not to exceed 1/10 of the 96-hour median tolerance limit obtained from continuous flow bio-assays where the dilution water and toxicant are continuously renewed except that other application factors may be used in specific cases when justified on the basis of available evidence and approved by the appropriate agency.
D AGRICULTURAL. Such as livestock watering, irrigation and spraying.	The average of any series of 10 consecutive samples shall not exceed 5000 nor shall 20% of the samples examined exceed 10,000. The average fecal coliform density for the same 10 consecutive samples shall not exceed 1000.	Not less than 3 at any time.	No objectionable unnatural turbidity, color, or deposits in quantities sufficient to interfere with the designated use.	Floating solids: None of unnatural origin. Residues: No evidence of such material except of natural origin. No visible film of oil, gasoline or related materials. No globules of grease.	Conform to current USPHS Drinking Water Standards as related to toxicants. Toxic and deleterious substances shall be less than those which are or may become injurious to the designated use.
E COMMERCIAL AND OTHER. Such as navigation, hydroelectric and steam generated electric power and uses not included elsewhere in standards.	The average of any series of 10 consecutive samples shall not exceed 5000 nor shall 20% of the samples examined exceed 10,000. The average fecal coliform density for the same 10 consecutive samples shall not exceed 1000.	Present at all times in sufficient quantities to prevent nuisance.	No objectionable unnatural turbidity, color, or deposits in quantities sufficient to interfere with the designated use.	Floating solids: None of unnatural origin. Residues: No evidence of such material except of natural origin. No visible film of oil, gasoline or related materials. No globules of grease.	Limited to concentrations less than those which are or may become injurious to the designated use.

APPENDIX D (Continued)

MICHIGAN WATER QUALITY STANDARDS

* For the Great Lakes and connecting waters no heat load in sufficient quantity to create conditions which are or may become injurious to the public health, safety or welfare; or which are or may become injurious to domestic, commercial, industrial, agricultural, recreational or other uses which are being or may be made of such waters; or which are or may become injurious to the value or utility of riparian lands; or which are or may become injurious to livestock, wild animals, birds, fish or aquatic life or the growth or propagation thereof.

6 TOTAL DISSOLVED SOLIDS (mg/l)	7 NUTRIENTS Phosphorus, ammonia, nitrates, and sugars	8 TASTE & ODOR PRODUCING SUBSTANCES	9 * TEMPERATURE (°F)	10 HYDROGEN ION (pH)	11 RADIOACTIVE MATERIALS
FOR GREAT LAKES & CONNECTING WATERS: Total Dissolved Solids: The maximum shall not exceed 200. Chlorides: The monthly average shall not exceed 50. A monthly average of 10 is a desirable limit where existing conditions are less than 10. FOR INLAND WATERS: Total Dissolved Solids: Shall not exceed 500 as a monthly average, nor exceed 750 at any time. Chlorides: The monthly average shall not exceed 125.	Nutrients originating from industrial, municipal, or domestic animal sources shall be limited to the extent necessary to prevent adverse effects on water treatment processes or the stimulation of growths of algae, weeds and slimes which are or may become injurious to the designated use.	Concentrations of substances of unnatural origin shall be less than those which are or may become injurious to the designated use. Monthly average phenol concentration less than 0.002 mg/l - maximum concentration limited to 0.005 mg/l for a single sample.	The maximum natural water temperature shall not be increased by more than 10°F.	pH shall not have an induced variation of more than 0.5 unit as a result of unnatural sources.	An upper limit of 1000 picocuries/liter of gross beta activity (in absence of alpha-emitters and Strontium-90). If this limit is exceeded the specific radionuclides present must be identified by complete analysis in order to establish the fact that the concentration of nuclides will not produce exposures above the recommended limits established by the Federal Radiation Council.
Total Dissolved Solids: Shall not exceed 500 as a monthly average nor exceed 750 at any time. Chlorides: The monthly average shall not exceed 125.	Nutrients originating from industrial, municipal, or domestic animal sources shall be limited to the extent necessary to prevent the stimulation of growths of algae, weeds and slimes which are or may become injurious to the designated use.	Concentrations of substances of unnatural origin shall be less than those which are or may become injurious to the designated use.	The maximum natural water temperature shall not be increased by more than 10°F.	Maintained within the range 6.5-8.8 with a maximum induced variation of 0.5 unit within this range.	Standards to be established when information becomes available on deleterious effects.
Limited to concentrations less than those which are or may become injurious to the designated use.	Nutrients originating from industrial, municipal, or domestic animal sources shall be limited to the extent necessary to prevent the stimulation of growths of algae, weeds and slimes which are or may become injurious to the designated use.	Concentrations of substances of unnatural origin shall be less than those which are or may become injurious to the designated use.	90°F maximum	Maintained within the range 6.5-8.8 with a maximum induced variation of 0.5 unit within this range.	Standards to be established when information becomes available on deleterious effects.
Limited to concentrations less than those which are or may become injurious to the designated use.	Nutrients originating from industrial, municipal, or domestic animal sources shall be limited to the extent necessary to prevent the stimulation of growths of algae, weeds and slimes which are or may become injurious to the designated use.	Concentrations of substances of unnatural origin shall be less than those which are or may become injurious to the designated use.	90°F maximum.	Maintained within the range 6.5-8.8 with a maximum induced variation of 0.5 unit within this range.	Standards to be established when information becomes available on deleterious effects.
Standards to be established when information becomes available on deleterious effects.	Nutrients originating from industrial, municipal, or domestic animal sources shall be limited to the extent necessary to prevent the stimulation of growths of algae, weeds and slimes which are or may become injurious to the designated use.	Concentrations of substances of unnatural origin shall be less than those which are causing or may cause taint in the flesh of fish or game.	(Ambient / Allowable increase / Maximum limit) Intolerant fish - cold water species: 32° to nat. max. / 10° / 70° Intolerant fish - warm water species: 32° to 35° / 15°; 36° to nat. max. / 10° / 85° Tolerant fish - warm water species: 32° to 59° / 15°; 60° to nat. max. / 10° / 87°	Maintained between 6.5 and 8.8 with a maximum artificially induced variation of 1.0 unit within this range. Changes in the pH of natural waters outside these values must be toward neutrality (7.0).	Standards to be established when information becomes available on deleterious effects.
Less than 700 dissolved minerals. Maximum percentage of sodium 60% as determined by the formula $\frac{(Na \times 100)}{(Na+Ca+Mg+K)}$ when the bases are expressed as milliequivalents per liter.	Nutrients originating from industrial, municipal, or domestic animal sources shall be limited to the extent necessary to prevent the stimulation of growths of algae, weeds and slimes which are or may become injurious to the designated use. NO_3 concentrations shall conform to USPHS Drinking Water Standards.	Concentrations of substances of unnatural origin shall be less than those which are or may become injurious to the designated use.	Not applicable	pH shall not have an induced variation of more than 0.5 unit as a result of unnatural sources.	An upper limit of 1000 picocuries/liter of gross beta activity (in absence of alpha-emitters and Strontium-90). If this limit is exceeded the specific radionuclides present must be identified by complete analysis in order to establish the fact that the concentration of nuclides will not produce exposures above the recommended limits established by the Federal Radiation Council.
Limited to concentrations less than those which are or may become injurious to the designated use.	Nutrients originating from industrial, municipal, or domestic animal sources shall be limited to the extent necessary to prevent the stimulation of growths of algae, weeds and slimes which are or may become injurious to the designated use.	Concentrations of substances of unnatural origin shall be less than those which are or may become injurious to the designated use.	The maximum natural water temperature shall not be increased by more than 10°F.	Maintained within the range 6.5-8.8 with a maximum induced variation of 0.5 unit within this range.	Standards to be established when information becomes available on deleterious effects.